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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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Journal of Sedimentary Petrology

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Multivariate analysis of mineralogic, lithologic, and chemical composition of rock bodies. By W. C. Krumbein and John W. Tukey.

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Articles submitted for publication to the *Journal of Sedimentary Petrology* should have a prefatory abstract and sufficient postage should be sent by the author to pay the return of the manuscript as it has been found that many articles require more or less revision before publication.

Persons who are not members of the Society of Economic Paleontologists and Mineralogists or are not subscribers to the *Journal of Sedimentary Petrology* but who desire to publish an article in the *Journal,* should have some member of the Society of Economic Paleontologists and Mineralogists or some member of the American Association of Petroleum Geologists sponsor the article. Members of these Societies are given preference in publication.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 26, NO. 2, PP. 103–110
FIG. 1, JUNE, 1956

GRAIN-SIZE ANALYSIS OF JACKSONIAN SEDIMENTS OF MISSISSIPPI AND ADJACENT AREAS

MING-SHAN SUN
New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico

ABSTRACT

The Jacksonian sediments concerned in this study crop out in east Texas, Louisiana, Mississippi, and western Alabama for about seven hundred miles in a narrow strip which is approximately parallel to the strand line of the Mississippi embayment. According to the nomenclature of Shepard (1954), the predominant types of sediments are sand, clayey silt, clayey sand, and sand-silt-clay. The less common types are silty sand, clay, sandy clay, sandy silt, and silty clay. There is no silt. The environment of deposition ranges from outer shelf, inner shelf, channels, bays near narrows, and deltaic, to beach sand. Most of the sediments are predominant in fine admixtures, and are normal-sorted. Well-sorted and poorly-sorted sediments are common. The subdivision of the Jacksonian sediments of Louisiana cannot be made according to their size composition. However, it is possible to subdivide the Jacksonian sediments of Mississippi according to their size composition. The transgression of the Jacksonian sea is interpreted by the change of grain size of the sediments.

METHOD OF STUDY

A total of 105 samples was analyzed. The calcareous content of the samples was removed by using 25 percent hydrochloric acid. The clastic material above .062 mm was weighed and sieved into grades. The clastic material below .062 mm was analyzed by the pipette method. The National Research Council grain-size scale (1947) was used. When authigenic pyrite was present, the sample was treated with warm 50 percent nitric acid in order to remove that mineral.

Cumulative curves of all the samples were plotted on the phi-scale, and the medians, first quartiles, and the third quartiles of the samples were derived from these curves. Incomplete quartile measures were obtained from some of the Yazoo samples whose cumulative weight percentages above .0039 mm were less than 25. Histograms of the samples were also plotted. The maxima, and the secondary maxima of some samples, were located on such histograms. The types of sediments were differentiated by plotting the data on the sand-silt-clay triangular diagram according to the nomenclature proposed by Shepard (1954). The mineral grains of the sediments were identified largely by optical method.

GENERAL DISCUSSION

Of the 105 samples analyzed, the maximum grain size was found to be in the grade of 8–4 mm. The calcareous content ranges from 0.13 to 91.55 percent. The clay portion ranges from 0.48 to 93.70 percent. The silt portion ranges from 0.71 to 75.12 per cent. The sand portion ranges from 0.19 to 99.25 percent. The gravel portion ranges from 0.39 to 6.07 percent. A summary of the size composition of the sediments of each stratigraphic unit of the Jacksonian sediments is shown in table 1.

Generally, fine sediments are likely to occur far away from the source, in deep water, near the bank of a bay, or in stagnant water adjacent to channels of a bay. On the other hand, coarse sediments may occur close to the source of supply, along the channels of a bay, or on a beach. A sediment can be formed by mixing of two types of sediments. A poorly-sorted sediment can be reworked by the winnowing action of the currents and attain a higher degree of sorting. On the other hand, a well-sorted sediment can be mixed with a fine-grained sediment and become poorly sorted. All such environments of conditions under which a particular sediment is deposited can be

interpreted by studying the grain-size composition of such sediment. For instance, the histograms of the sediments of the Tullos member of Louisiana show two maxima, indicating that such sediments were formed by the mixing of two types of sediments. The Pachuta member of Mississippi represents a mixed sediment of the well-sorted Cocoa sand and the calcareous Shubuta sediments. The histogram of the Pachuta member is very similar to that of Cocoa sand, yet it contains about 50 percent calcareous material. The average calcareous content of Cocoa sand is less than 1 percent. The calcareous content of Shubata is as high as 85 percent. Histograms show that most of the Jacksonian sediments possess only one maximum. Most of the sediments are predominant in fine admixtures.

Calcareous material is a very important constituent of the Jacksonian sediment; it ranges from less than 1 percent to 91.55 percent. It occurs mainly as shell fragments and foraminifera tests, but a small amount of chemically precipitated calcium carbonate is also present. The shell and foraminifera tests were probably incorporated into the sediments where they lived. However, some broken shell fragments and some pitted and striated foraminifera tests could have been transported for some distance before deposition. In such case, the shell fragments and some

TABLE 1. *Summary of quartile measures, median, coefficient of sorting, and skewness of Jacksonian sediments*

Locality	Formation or member	Q_3 (25%)		Q_1 (75%)		Md (50%)		$So = \sqrt{\frac{Q_3}{Q_1}}$		$Sk = \frac{Q_3Q_1}{Md^2}$	
		Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
East Texas	Caddell	.0869	.1375–.0311		.0095–<.0039	.0536	.1063–.0059		2.891–>8.292		.801–<.045
	McElroy	.1203	.2000–.0281		.1250–<.0039	.0989	.1562–.0101		1.096–>1.452		1.155–<.957
Louisiana	Danville	.0327	.0334–.0313	.0041	.0059–.0022	.0192	.0225–.0148	2.996	2.303–3.896	.349	.365–.335
	Verda	.0434	.0625–.0312	.0053	.0075–.0035	.0187	.0265–.0117	2.875	2.543–3.201	.686	.934–.502
	Union Church	.0511	.0688–.0334	.0039	.0047–.0030	.0297	.0438–.0156	3.582	3.337–3.826	.291	.412–.169
	Tullos	.0449	.0563–.0334		.0094–<.0039	.0203	.0250–.0156		2.447–up		.847–down
	Moodys Branch	.0405	.0595–.0313	.0096	.0225–.0020	.0223	.0407–.0117	2.592	1.626–3.956	.761	1.452–.326
W. Mississippi	Yazoo[1]	.0851	.1000–.0540		.0281–<.0039	.0250	.0781–.0101		1.827–>3.992		1.006–<.432
	Marl[1]	.1032	.1063–.1000	.0059	.0067–.0051	.0292	.0334–.0250	4.205	3.982–4.428	.727	.816–.638
	Greensand[1]	.2488	.3250–.2125	.0878	.1150–.0296	.1737	.2062–.1375	1.817	1.415–2.833	.764	1.231–.230
	Greensand[3]	.2100	.2250–.1625	.0824	.1094–.1025	.1550	.1688–.1250	1.998	1.363–4.243	.727	.980–.107
	Cockfield	.1454	.1750–.1157		.0265–<.0039	.0687	.1156–.0218		2.570–up		.347–down
E. Mississippi and W. Alabama	Shubuta	.0081	.0086–.0075		.1375–<.0034	.0038	.0039–.0036		1.243–>7.669		.831–<.034
	Pachuta	.1811	.3000–.0094		.2315–.1375	.2112	.2625–.1562	1.204	1.124–1.296	1.138	1.303–.982
	Cocoa	.2688	.3000–.2125	.1875	.2315–.1375	.2112	.2625–.1562	1.204	1.124–1.296	1.138	1.303–.982
	North Creek	.0533	.1063–.0234	.0091	.0265–.0025	.0285	.0625–.0094	2.814	1.811–3.682	.618	.802–.375
	Greensand	.3550	.7000–.2250	.0605	.1000–.0117	.2075	.2625–.1500	2.347	1.500–4.183	.308	1.000–.075
	Gosport	.4563	.6500–.3000	.2438	.3000–.1750	.3188	.4000–.2500	2.260	1.304–1.472	1.076	1.219–.840
	Lisbon[2]	.0281		.0055		.0140				.789	

Note: 1. Samples analyzed without acid treatment.
2. Same number of samples of Greensand, but analyzed with acid treatment.
3. Only one representative sample of the fine-grained Lisbon sediments was analyzed.

foraminifera tests may be considered as clastic materials. A few of the Jacksonian sediments can be called marl, chalk, or arenaceous chalk, but the present study deals primarily with their clastic constituents.

Numerous variegated glauconite grains are present in the Jacksonian sediments. In a few samples they are predominant over the quartz grains. The dark olive-green glauconite grains are very resistant to acid treatment. However, the light-green, spongy variety, and some incipiently developed glauconite are rather weak and tend to break or disintegrate in solution. Therefore, a part of the glauconite grains were analyzed not in their original size, but in the size of their disintegrated particles. The incipient glauconite grains are partly mica flakes and partly clayey materials.

The bulk of the clastic fractions of the Jacksonian sediments contain quartz grains, rock fragments of various kinds, feldspar grains, mica flakes, glauconite, some shell fragments, foraminifera tests, and a small amount of heavy minerals (Sun, 1954). Montmorillonite is the major clay mineral of the clay fraction. The relation between the grain size and the mineralogical composition of the sediments is not included in this study.

The nomenclature of stratigraphy used in this paper is that of Ellisor (1933) for the Jacksonian sediments of Texas, Fisk (1938) for the Jacksonian sediments of Louisiana, and Murray (1947) for the Jacksonian sediments of Mississippi and adjacent areas.

CLASSIFICATION ON THE BASIS OF SAND-SILT-CLAY RATIOS

The Jacksonian sediments concerned in this study crop out in east Texas, Louisiana, Mississippi, and western Alabama for about seven hundred miles in a narrow strip which is approximately parallel to the strand line of the Mississippi embayment. Over this extended area, the sediments show a distinct diversity in size characteristics. The sediments are classified on the basis of their sand-silt-clay ratios. The nomenclature (fig. 1-D) which was proposed by Shepard (1954) is applied to the Jacksonian sediments. The calcareous materials are not included in the calculation of the sand-silt-clay ratios.

In east Texas, the Caddell and McElroy formations represent the lower portion of the Jacksonian sediments. Samples of the middle Caddell formation of Brazos Co., Texas (fig. 1-A) are generally rich in sand and silt, which vary in proportion alternately through the columnar section. The clay fraction ranges from 17 to 35 percent, although two samples have about 45 and 40 percent respectively. The types of sediments are clayey sand, sand-silt-clay, silty sand, and clayey silt. The median of such sediments shows that the middle Caddell formation is predominantly very fine sand and very coarse silt. Histograms show that the Caddell formation tends to have two maxima, one at .0625 mm and the other at about .0039 mm. This indicates that parts of the Caddell formation are mixtures of coarse silt fraction and clay fraction. The sorting of the sediments is rather normal, with few samples which are largely fine admixtures and poorly sorted. According to Trask (1932), the coefficient of sorting of well-sorted sediments is less than 2.5, that of a normal-sorted sediment is greater than 4.5. The skewness shows that most of the middle Caddell formation sediments are predominant in fine admixtures.

Samples of the McElroy formation from Madison Co., Texas, are comparatively coarser than those of the middle Caddell formation. They are well-sorted sediments with coefficients of sorting ranging from 1.096 to 1.452. Only one sample indicates a poorly sorted sediment. The skewness shows that the coarse and fine admixtures are about equal. Very fine sand predominates. The histograms show the maximum to be at .0625 mm. The types of sediments are sand, one sample of silty sand, and one sample of clayey silt. It seems that all the sediments of the middle Caddell

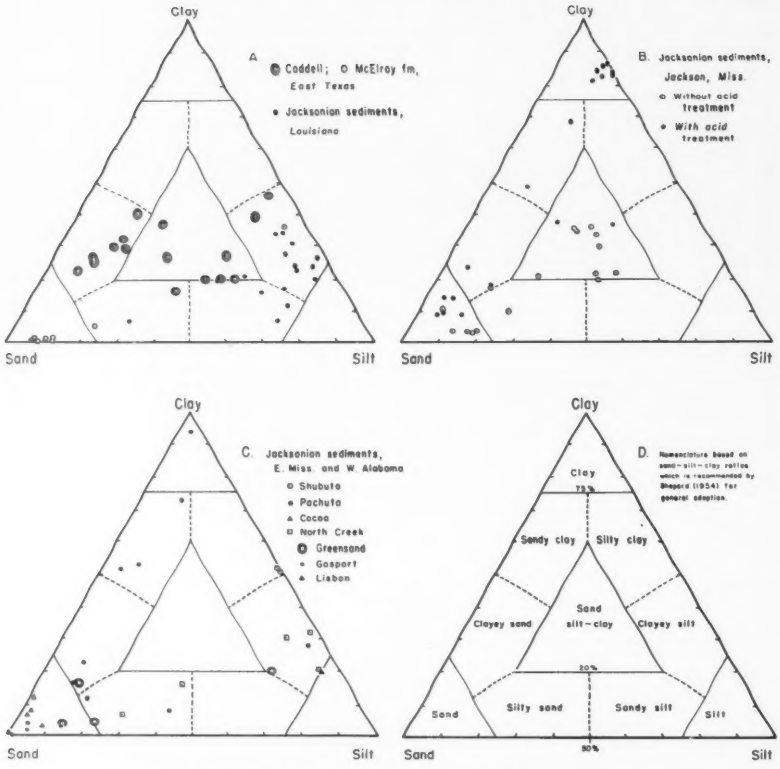

FIG. 1.—Triangular diagram showing the sand-silt-clay composition of the Jacksonian sediments.

formation and the McElroy formation are tidal flat or upper neritic (inner shelf) at the west end of the Missisippi embayment. The well-sorted sediments of the McElroy formation are probably the result of winnowing action by tidal currents or waves upon the poorly-sorted sediments. The fine-grained admixtures resulting from the re-working were carried away in suspension load and deposited elsewhere. Local variations in size are clearly shown by two samples which are located only 5 feet apart within the same horizon, yet their clay content is quite different. One sample contains 22.85 percent clay, whereas the other sample contains 40.12 percent.

Most of the Louisiana samples from the top to the bottom of the Jacksonian section have maxima at .0156 mm. One sample of the Union Church has a maximum at .0313 mm. Two samples of Tullos have two maxima; one sample has maxima at .0625 mm and .0156 mm, and the other sample has maxima at .0313 mm and .0039 mm. This indicates that sedi-

ments of Tullos are mixtures of two types of sediments. The sorting of the Louisiana samples is normal, with three samples which are well-sorted. All the samples show predominance of fine admixtures, except one sample of Moodys Branch which has predominance in coarse admixture. The average clay content is about 20 percent. The Jacksonian sediments of Louisiana have been described as difficult to subdivide or differentiate in the field. The similarity of the size characteristics of these sediments reflects the similar appearance of the sediments as seen at the outcrops. Although the Jacksonian sediments of Louisiana have been subdivided into various members, the grain-size analysis does not provide additional evidence for such subdivision. However, some silty sand lentils can be used as reference in order to differentiate these members in the field. The types of sediments are clayey silt, sandy silt, silty sand and sand-silt-clay (fig. 1-A). Most of such sediments are commonly called silty mud.

In the western part of Mississippi there are two distinct types of Jacksonian sediments (fig. 1-B). The Moodys Branch formation below is predominantly sand, and the Yazoo formation above is clay. Glauconite grains constitute an important part of the sand fraction of the Moodys Branch formation. Its amount can be as high as 40 percent. It is usually less abundant than quartz grains, except in a few samples where glauconite is greatly concentrated. Glauconite is also present in the Yazoo formation, and varies in quantity up to about 15 percent. Comparatively, the glauconite grains in the Yazoo formation are spongy and incipiently developed and likely to break into small grains of fine silt size during the acid treatment of the grain-size analysis. Therefore, the fine silt fraction of the Yazoo samples is increased. The cumulative curves of the Yazoo samples do not show any median or first quartile, because the samples are not coarse enough. However, their histograms show distinct although not prominent maxima at 0.313 mm.

The Moodys Branch formation is subdivided into a marl member above and greensand member below. The marl member is rich in clay, and it represents a transitional sediment between its underlying greensand member which contains about 10 percent clay, and the overlying Yazoo formation which contains about 80 percent clay. One sample of the marl member, which is just above the greensand member, shows two maxima in its histogram. One maximum is at .125 mm and the other at .0313 mm. This sample contains 81.81 percent clay. The maximum at .125 mm indicates a coarse admixture of the greensand member. The maximum of the greensand member is located at .125 mm. The boundary between the marl member and the greensand member is gradational and not conspicuous at the outcrop. Also the boundary between the marl member and the Yazoo formation is not distinct at the outcrop. The sediments of the marl member resemble those of the mudlumps at the mouths of the Mississippi River. The sediments of the mudlumps contain about 85 percent of materials finer than .01 mm, of which about 60 percent is clay. It seems that there is some resemblance of the environment of deposition of both the marl member and the mudlumps. The type of sediments of the greensand member are sand, clayey sand, and sand-silt-clay. Most likely it was deposited in the inner shelf (upper neritic zone) and mixed with marine shell fragments, foraminifera tests, and a little clayey material. The samples of the Cockfield formation, which underlies the Jacksonian sediments, show a transitional or mixed type of sediment. Their histograms show two maxima, one at .0625 mm and the other at .0039 mm.

Without acid treatment in the grain-size analysis, the samples of the Jacksonian sediments of the western part of Mississippi also can be classified into two

types (fig. 1-B). The Moodys Branch formation is mainly sand, and the Yazoo formation is mainly sand-silt-clay, with one intermediate silty sand of the upper part of the greensand member. With acid treatment, one sample of Cockfield is plotted as sand-silt-clay, but without acid treatment, the same sample is plotted on the boundary line between clayey sand and silty sand. Without acid treatment the median of the Yazoo samples is at .0250 mm, corresponding to medium silt, and histograms show that the maxima of such Yazoo samples are at .0625 mm. Without acid treatment, only two samples of the Yazoo formation are coarse enough, so that quartile measures can be derived from their cumulative curves. These two samples represent sediment which is normal-sorted and slightly predominant in coarse admixture. Samples of the marl member represent either normal- or poorly-sorted sediments. Histograms of such samples show maxima at about .0625 mm, which is the same as in the Yazoo formation samples. The maximum of the greensand is at .125 mm, which is the same as in the sample analyzed with acid treatment. The maximum of the Cockfield sample is at .125 mm.

The difference in size characteristics between the samples with and without acid treatment is attributed to the fact that all calcareous materials are included in the samples which were analyzed without acid treatment. The calcareous materials are chiefly foraminifera tests which are about .0625 mm in diameter. Without acid treatment, such tests are included in the sieve analysis, and they build up the maximum of the sample at .0625 mm. The foraminifera tests are predominant in the Yazoo samples and also in the marl member of the Moodys Branch formation.

Samples from eastern Mississippi and western Alabama generally have a high content of calcareous materials. The sediments of the Moodys Branch formation crop out in many places without much conspicuous change in lithology except that they become coarser. The Yazoo formation, however, becomes diverse and can be subdivided into four members (Murray, 1947). The Yazoo formation grades into Ocala limestone east of the Alabama River.

North Creek, the lowest member of the Yazoo formation, is predominantly clayey silt. The sorting of the sediments is nearly normal. The average median is at .0285 mm, corresponding to medium silt. The Cocoa sand is well-sorted beach sand. Its average median is at .221 mm, corresponding to fine sand. The amount of both fine and coarse admixtures is small. Its histogram shows a maximum at .125 mm. One sample indicates a mixed sediment of both the Cocoa sand and the North Creek member. It represents a poorly-sorted sediment. The Pachuta member represents a mixed sediment probably derived from the underlying Cocoa sand and the overlying Shubuta member. It occurs in all divisions over the triangular diagram, figure 1-C. One sample of the Pachuta member shows two maxima in its histogram. One maximum is at .125 mm, indicating the mixed portion of its underlying Cocoa sand, and one maximum is at .0029 mm, indicating a fine admixture of clay. One sample of the Pachuta member has the same size characteristics as its underlying Cocoa sand, but this sample contains 52.35 percent calcareous materials. The calcareous content of the Cocoa sand is less than 1 percent. Samples of the Shubuta member represent calcareous sediment which is rich in silt and clay, with very little sand. The Shubuta member may represent a deposit of the outer shelf (lower neritic zone), where silt and clay are the predominant clastic constituents. The variation of size characteristics provides rather adequate evidence for the subdivision of the Yazoo formation in eastern part of Mississippi and western Alabama into four members.

A few samples of Gosport sand, which underlies the Moodys Branch formation

in western Alabama, are included in the grain-size analysis for comparison purpose. The size characteristics of both the greensand member of the Moodys Branch formation and the Gosport sand are very similar. Both sediments contain glauconite and can be called greensand. The maximum of Gosport is at .25 mm. Some samples of the greensand member from eastern Mississippi and western Alabama have maxima at .25 mm, whereas others have maxima at .125 mm. There is a marked difference in size characteristics between the Gosport sand and the Lisbon formation (fig. 1-C).

GRAIN SIZE AND TRANSGRESSION

On the basis of the change of grain size of the samples collected from Mississippi and western Alabama, it can be implied that the Jacksonian sediments were deposited during the transgression of the Jacksonian sea, that is, while the sea level was rising and the strand line of the Mississippi embayment was shifting landward. The Cockfield sample of Jackson, Mississippi, and the Lisbon sample of the Little Stave Creek locality represent the end of the outer neritic zone of deposition of the Claiborne sea. A rather rapid regression of the Claiborne sea resulted in the deposition of coarse sediments of the Moodys Branch formation on top of the fine-grained Lisbon and Cockfield formation. The coarse sediments of the Moodys Branch formation and the Gosport sand represent the beginning of deposition of the Jacksonian sediments.

It is shown in figure 1-B that the sediments of the Moodys Branch formation become finer toward the Yazoo formation.

The types of the Jacksonian sediments range from sand, clayey sand, sand-silt-clay, sandy clay, into clay (fig. 1-B). There is a decrease in size from the lower part of the greensand member to the clay of the Yazoo formation. This decrease in size indicates a change of environment of deposition from shallow water to deep water. There was pulsation of the Jacksonian sea level, such as indicated by the Cocoa sand, but as a whole there seems to be little doubt of the Jacksonian transgression.

On the basis of size characteristics and lithology, the Gosport sand is considered to be equivalent to the lower part of the Moodys Branch formation of Jackson, Mississippi. On the basis of paleontology, there seems to be no strong evidence to indicate that the Gosport sand should be considered to have the same age as its underlying Lisbon formation (Bandy, 1949).

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FIGS. 1–3, JUNE, 1956

THE ORIGIN OF CALCAREOUS OOLITHS

P. H. MONAGHAN AND MELBA L. LYTLE
Humble Oil & Refining Company, Houston, Texas

ABSTRACT

Laboratory studies were undertaken to discover mechanisms which might explain the origin of calcareous ooliths in nature. Calcium carbonate was precipitated from sea water by evaporation, by addition of precipitating agents and by the growth of sulfate-reducing bacteria. The effect of the major ions in sea water on the form of the calcium carbonate precipitate was also studied.

These experiments showed that calcareous ooliths can be formed by chemical precipitation from sea water and by the growth of sulfate-reducing bacteria in sea water. The presence of magnesium ion in sea water causes calcium carbonate to precipitate as aragonite rather than calcite.

An environment in which fresh waters high in carbonate ion flow into a shallow sea would reproduce the laboratory conditions for chemical precipitation of calcareous ooliths. Such a mechanism does not appear to be responsible for any large present day deposits.

Environments where sulfate-reducing bacteria might be important in the origin of calcareous ooliths should be characterized by deficiency of oxygen, increased pH and presence of hydrogen sulfide or sulfide salts. Such environments might be highly localized.

INTRODUCTION

The unusual rounded form of oolitic grains has attracted the curiosity and study of scientific workers for over a century.

Because the pores between oolitic grains constitute one type of porosity in limestone and dolomite beds and since porosity is a requisite for the accumulation of petroleum, the origin and mode of occurrence of such grains are of importance to the petroleum geologist. Oil and gas have been discovered in oolitic beds in a number of petroliferous provinces. In the search for this type of porosity it becomes necessary to know as much as possible about the environments in which ooliths may be formed.

Definition of Terms

A discussion of oolites will be facilitated by the definition of a number of terms, which unfortunately are not always used with consistency in the literature. The following definitions are not given as authoritative but merely to clarify the use of the terms in this report.

spherulite—spherical or ellipsoidal particles having crystals radially oriented (shown by an extinction cross between crossed nicols)

oolith—spherulite having concentric banding.

oolitic grain—an oolith.

Occurrence and Theories of Origin of Oolites

Ooliths occur as surface deposits in various parts of the world. Among the deposits which have been studied and reported in the literature are those of the Canary Islands, the Bahama Banks, the southern coast of Florida, the Red Sea and the Great Salt Lake. [Illing (1954), Linck (1903), Mathews (1930), Quiring (1944), Rothpletz (1892), Smith (1940), Thorp (1939), Vaughan (1914).] Ooliths are also found in many ancient consolidated sediments. It is of interest that all of the Recent surface deposits which have been studied are aragonite, whereas the ancient ones are calcite.

Theories for the formation of ooliths which have been advanced by previous investigators can be grouped into three main categories: ooliths are (1) chemically precipitated from solution, (2) built by secretions from plants and animals,

TABLE 1.—*Precipitation of calcium carbonate from sea water*

Sample Volume—25 ml
Temperature —27°C

Precipitating Agent	Remarks	X-Ray Analysis
1.0 M Na_2CO_3 solution	Gelatinous ppt. formed immediately. After aging for 2 weeks, changed to fine spherulites and ooliths	Amorphous Aragonite
1.0 M K_2CO_3 solution	Gelatinous ppt. formed immediately. After aging 2 weeks, changed to fine spherulites and ooliths	Amorphous Aragonite
1.0 M $(NH_4)_2$ CO_3 solution	Soln. turned cloudy. After 24 hours ppt. consisted of fine spherulites	Aragonite
1.0 M NaOH solution	Fine ppt. formed, composed of needle-like crystals	Aragonite
6.0 M NH_4 OH solution	Fine ppt. formed, composed of needle-like crystals	Aragonite
Evaporation 26–100°C	Fine ppt. formed after volume decreased ⅓ (approx.) Ppt. composed of needle-like crystals	Aragonite

(3) built by physical aggregation of small particles rolling around on the bottom of the sea.

It has been known for a number of years that the crystalline form of certain substances can be influenced by the conditions of crystallization. Such a substance is calcium carbonate, and a number of investigators have reported experiments which produced spherulitic particles of calcium carbonate [Brooks (1950), Harting (1871), Lengyel (1937)].

The present work has undertaken to discover mechanisms which might explain the origin of ooliths in nature. Laboratory experiments were planned to confirm and extend the results of previous investigators and to test various hypotheses which appeared plausible for the origin of calcareous ooliths.

LABORATORY WORK

Origin of Ooliths by Aggregation of Aragonite Muds through Motion

Some investigators have held that ooliths could be formed by mechanical aggregation of lime muds and shell fragments through motion on the sea bottom. An experiment was performed to check this hypothesis in the laboratory. A sample of fine aragonite mud from near Andros Island in the Bahamas was placed in a shallow tray and covered with sea water. This tray was rocked continuously to simulate wave action. Samples were removed periodically and examined for the presence of ooliths. The experiment was continued for 2 months. Some few rounded aggregates were formed, but these exhibited no radial or concentric structure and often disintegrated into the individual particles during transfer to a microscope slide for examination.

It is felt that mechanical aggregation of aragonite muds is not a probable mechanism for oolith formation.

Chemical Precipitation of Calcium Carbonate

One hypothesis of the origin of ooliths is that they are chemically precipitated from sea water. To test this hypothesis, calcium carbonate was precipitated from sea water in a number of ways. Several small samples of sea water from areas of oolith occurrence in the Bahama Islands were available, but because of their small volume, water from the Gulf of Mexico was used in most experiments. Both the Bahamas water and the Gulf water are similar in composition to normal sea water. The Bahamas water, however, had a higher salinity than the Gulf water.

Calcium carbonate was precipitated from sea water by evaporation at temperatures from 26°C to 100°C, and by the addition of precipitating agents which increase the carbonate ion concentration either through the direct addition of car-

bonate ion or by raising the pH of the solution. The precipitates were examined with the polarizing microscope and X-ray analyses were made. The results of these experiments are shown in table 1.

These results indicated that spherulitic or oolitic particles of calcium carbonate could be precipitated from sea water but that an increase in carbonate ion concentration greater than that obtained by merely raising the pH of these samples was necessary. X-ray analyses showed the precipitates to be aragonite.

Effect of Increased Carbonate Ion Concentration on the Form of the Calcium Carbonate Precipitate.—Additional experiments were performed to determine the minimum concentration of carbonate ion which would form spherulites. Sodium carbonate was chosen as a source of carbonate ion.

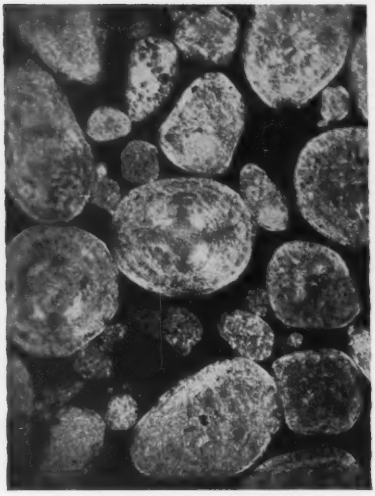
Solutions containing different concentrations of sodium carbonate were added to 25 ml samples of sea water. The volume of Na_2CO_3 solution added was in each case sufficient to combine with all of the calcium ion present in the sea water. These mixtures were allowed to stand, and the precipitates which formed were examined under the polarizing microscope and with X-rays. Table 2 contains the results of these experiments.

These experiments showed that if the concentration of carbonate ion in the sea water at the time of precipitation was greater than 0.002 mol per liter the precipitate contained spherulites. If the carbonate ion concentration was less than 0.002 mol per liter, the precipitate contained needle-like crystals. As the carbonate ion concentration decreased, the radial orientation within the spherulites became less definite. In those cases in which an amorphous gel was formed initially, the concentric banding was most pronounced.

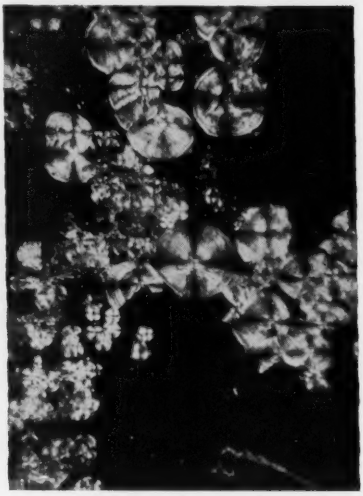
Comparison of Ooliths Prepared in the Laboratory with Natural Ooliths.—The oolitic-appearing particles prepared in the laboratory by the addition of carbonate ion to sea water were very similar to natural ooliths from the Bahamas area in both appearance and composition. Both materials are aragonite and contain nearly identical amounts of calcium and magnesium. The trace elements present as revealed by spectrographic analysis (performed by Laboratories of Humble Oil & Refining Co., Baytown) are the same in both materials. The materials also are similar in appearance when viewed with the polarizing microscope, as shown in Figure 1. The main point of difference is in the size of the particles. Those prepared in the laboratory varied from 0.03 to 0.1 mm in diameter whereas those occurring in the Bahamas are usually from 0.1 to 0.5 mm in diameter. It should be possible, however, to grow particles in the laboratory as large as those found in the Bahamas.

TABLE 2.—*The effect of carbonate ion concentration on form of $CaCO_3$ precipitated from sea water*

$CO_3^=$ conc. of mixture: Mols per liter	Examination of Precipitate	
	Appearance under Microscope	X-Ray Analysis
0.0167	Ooliths in amorphous masses	Aragonite, a basic magnesium carbonate
0.0123	Spherulites	Aragonite
0.0091	Spherulites	Aragonite
0.0067	Spherulites	Aragonite
0.005	Spherulites	Aragonite
0.0033	Spherulites	Aragonite
0.002	Spherulites, poorly defined	Aragonite
0.00091	Very small needles	



Bahamas A-5-1—mag. 50×



Laboratory preparation—mag. 50×

FIG. 1.—Thin sections of natural and laboratory ooliths, crossed nicol prisms.

Effect of Major Ions in Sea Water on Form of Calcium Carbonate.—An interesting question was raised by the fact that the ooliths prepared in the laboratory and most Recent natural marine calcium carbonate deposits were aragonite rather than the more stable form, calcite. Is one or more of the other ions in sea water responsible for the formation of aragonite?

Solutions were prepared each containing calcium and one other main constituent of sea water in the same concentration as in sea water. Calcium carbonate was precipitated by the addition of a 0.1 M solution of sodium carbonate. The resulting precipitate was examined by X-rays and the polarizing microscope. The results of these examinations are shown in table 3. Calcium ion alone, or calcium and sodium ions, calcium and potassium ions, and calcium and sulfate ions produced rhombic crystals of calcite. Calcium and magnesium ions, however, produced a precipitate which appeared to be an amorphous gel, but which transformed upon standing into spherulitic crystals of aragonite and calcium carbonate monohydrate.

A solution was prepared containing 1000 mg per liter of calcium ion and 3000 mg per liter of magnesium ion as chlorides. This solution was treated with 0.1 M Na_2CO_3 solution. The result was a gelatinous precipitate which changed to spherulites of aragonite and calcium carbonate monohydrate. The form of the precipitate was the same when the total concentration of calcium and magnesium ions was increased above that of sea water.

Thus it appears that the presence of magnesium ion in sea water causes the calcium carbonate to precipitate in a form other than calcite.

Precipitation of Calcium Carbonate by Sulfate-Reducing Bacteria

Although this work served to clarify partially the chemistry involved in the formation of ooliths, it did not show under what specific conditions ooliths may be formed on the Bahama Banks, for example. The results demonstrated that sea water could yield calcareous ooliths only if the pH and the carbonate ion concentration were increased sufficiently before precipitation occurred. The work did not,

however, suggest a likely agent for bringing about these changed conditions in an area such as the Bahama Banks. One agent which has been suggested in the older literature is denitrifying bacteria.

Prior to the work described in this report it had been observed in the course of experiments on the bacterial corrosion of steel that sulfate-reducing bacteria are capable of raising the alkalinity of the medium in which they are grown. This increase in alkalinity results presumably from the replacement of the strongly acidic sulfate radical by the relatively weakly acidic sulfide radical. The pH had been observed to reach values as high as 10, which is sufficient to precipitate calcium carbonate from sea water. These bacteria also produce carbon dioxide as a product of their metabolism, and this carbon dioxide could be a source of carbonate ion in a medium of high pH.

Sulfate-reducing bacteria thus appeared to offer a possible means of obtaining the increased alkalinity found in the previous experiments to be necessary for the formation of calcareous ooliths. A laboratory investigation of these bacteria and of their ability to produce ooliths from sea water under certain conditions was carried out.

Sulfate-reducing bacteria from two localities were used in these studies. The sulfate-reducing bacteria used in most of the experiments were isolated from a bottom sediment sample taken in one foot of water at the town of Grand Isle, La., in September, 1950.

The other bacteria used were found in a bottom sample of lime mud collected in the Bahamas region in August, 1950, which had been stored in a tightly sealed jar for over two years. This sample was taken from the center of the channel at the west end of South Bight, Andros Island.

One hundred milliliter portions of a Bahamas water sample were placed in each of six sterile 250 ml Erlenmeyer flasks. The flasks were divided into three groups and the following materials were added:

Group I. 1 ml of 50 percent sodium lactate, 25 mg $NaHCO_3$, mild steel coupon ($1'' \times 3'' \times \frac{1}{16}''$; wt. 25 g)

TABLE 3.—*Effect of ions in sea water on crystal form of $CaCO_3$ precipitated at room temperature*

Samples—50 ml volume, all cations as chlorides
15 ml of 0.1 M Na_2CO_3 solution added to all samples
Filtered ½ hour after precipitation

Sample Composition	Microscopic Examination		X-Ray Analysis After 44 days
	Immediately	After 44 days	
396 ppm. Ca^{++}	Rhombic crystals	Rhombic crystals	Calcite
396 ppm. Ca^{++} 11,000 ppm. Na^{+}	Rhombic crystals	Rhombic crystals	Calcite
396 ppm. Ca^{++} 1,300 ppm. Mg^{+}	Irregular masses of tiny particles. No pattern under crossed nicols. Appeared amorphous	Spherulites	Aragonite, $CaCO_3 \cdot H_2O$
396 ppm. Ca^{++} 378 ppm. K^{+}	Rhombic crystals	Rhombic crystals	Calcite
396 ppm. Ca^{++} 2,600 ppm. $SO_4^{=}$	Rhombic crystals	Rhombic crystals	Calcite

Group II. 1 ml 50 percent sodium lactate

Group III. 1 ml 50 percent sodium lactate, 1½" No. 36 iron wire.

All six flasks were inoculated with 1–2 ml of an anaerobic culture of sulfate-reducing bacteria from Grand Isle, La. Previous work on the corrosion of steel had indicated that the presence of iron in cultures increased the rate of growth of the bacteria. Iron was introduced into some of the cultures for the purpose of stimulating growth although free iron would not ordinarily be present in natural sediments.

One culture from each group was incubated at room temperature under aerobic conditions by placing a sterile cotton plug in the neck of the flask. The other culture from each group was incubated at room temperature under anaerobic conditions, obtained by suspending sterile 10 ml test tubes containing an alkaline pyrogallol solution from rubber stoppers which were sealed into the necks of the flasks with paraffin. Additional sodium lactate solution was added to some cultures during the incubation period.

These cultures of the bacteria are not comparable to those occurring naturally. In particular, the use of sodium lactate as a nutrient and of sodium pyrogallol as an oxygen absorbant may have caused the culture medium to have a higher pH, after incubation, than the natural environment of the bacteria. Utilization of sodium lactate by the bacteria might leave the sodium ion in solution as an alkaline residue. Likewise, sodium pyrogallol will absorb hydrogen sulfide and carbon dioxide gases, as well as oxygen gas, thus shifting the equilibrium of these acidic gases with the culture medium and leading to more alkaline conditions. Consequently, the increase in pH produced by the bacteria under natural conditions cannot be deduced from these experiments.

The cultures were observed periodically and examined with the microscope when any change in their appearance was apparent. Photomicrographs were taken and X-ray diffraction analyses were run on specimens of special interest.

The bacteria grew in all of the anaerobic cultures, with those in the cultures containing iron growing at a more rapid rate. The anaerobic culture of Group I, containing the iron coupon, turned very black, indicating a good growth of bacteria, but the large amounts of black iron sulfide masked any carbonates present. The anaerobic culture of Group III, containing iron wire, turned black, indicating bacterial activity and production of iron sulfide. This black color gradually disappeared and was replaced by a pink color and production of a white scum on the surface of the liquid. This scum consisted of many bacteria and some spherulites of aragonite. The anaerobic culture of Group II, containing only Bahamas water and an organic nutrient, became turbid, turned pink, and after a considerably longer period formed a few spherulites. X-ray analysis of the precipitate from this culture revealed the presence of aragonite, calcite, and sodium chloride.

The bacteria did not grow as well under aerobic conditions. There was no marked change in the appearance of the liquid in these cases, and no surface scum formed in these cultures.

A number of submarine cores from the Bahama Island area, collected in 1950, were examined for evidence of sulfate-reducing bacterial activity. Several cores of drewite mud had turned black and smelled of hydrogen sulfide, indicating that sulfate-reducers had been active in these samples. These samples still contained a small amount of connate water. Microscopic examination of the samples revealed a small number of viable bacterial forms, similar in appearance to the Grand Isle sulfate reducers, and a few spherulites.

One hundred milliliter portions of Bahamas water were inoculated with 4–5 grams of mud from a sample containing bacteria, and 2½ ml of 50 percent sodium lactate solution was added as an organic

nutrient. The cultures were incubated anaerobically using alkaline pyrogallol solution to remove the atmospheric oxygen.

After an initial slight blackening the solutions became quite turbid. After six weeks, a small amount of white scum formed on the surface. This scum consisted of bacteria, small acicular crystals, and a few large spherulites. Photomicrographs of some of these crystals are shown in figure 2. X-ray analysis showed the crystalline material to be aragonite.

The bacteria from the Bahamas area acted in a manner similar to the Grand Isle sulfate-reducers and caused the precipitation of spherulitic particles.

EXAMINATION OF SOME BAHAMAS SEDIMENT SAMPLES

In the Andros Island region of the Bahamas Banks the deposits of oolitic sand occur primarily north and south of the island and along the rims of the Banks. These ooliths are usually uniform in size (0.10–0.50 mm diameter). A portion of the submarine banks west of Andros Island is covered by deposits of very fine drewite containing a small amount of shell fragments and irregular pellets.

The samples of drewite which contained sulfate-reducers, also contained a few small spherulites. Two other samples of drewite mud collected in 1950 were sieved and the fractions larger than 200 mesh (75 microns) were thin sectioned.

These thin sections showed that the coarse fractions consisted of aragonite pellets and a few microfossils and shell fragments. However, small spherulites were embedded in a number of these pellets. Photomicrographs of such a pellet are shown in figure 3.

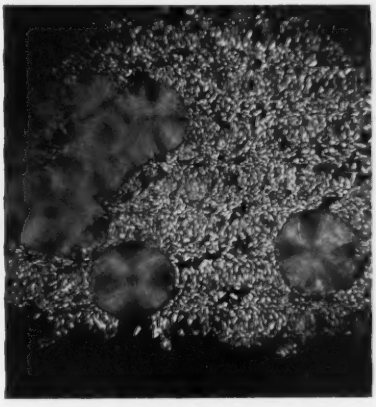
These embedded spherulites may have resulted from the growth of bacteria, but it cannot be determined whether they formed before the samples were brought into the laboratory or during storage.

CONCLUSIONS

Based on the behavior observed in the laboratory the following conclusions may be drawn:

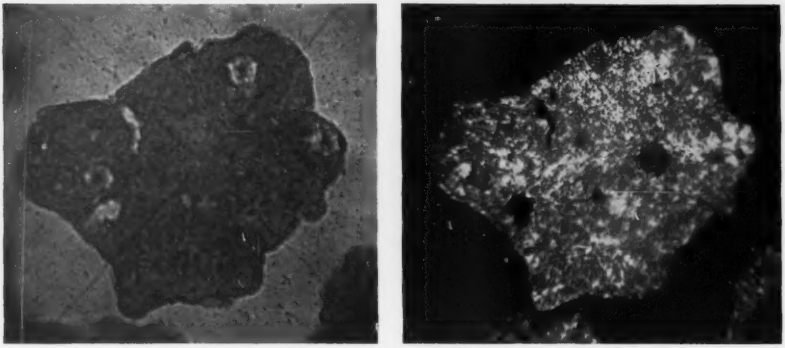
1. Calcareous ooliths may be prepared in the laboratory by chemical precipitation of calcium carbonate from sea water.
2. The concentration of carbonate ion at the time of precipitation must exceed 0.002 mol per liter, which is a greater concentration than is found normally in sea water.

X30



A X110 CNP

FIG. 2—Precipitate from culture of Bahamas bacteria grown in Bahamas water.



×220 ×220 CNP

FIG. 3.—Drewite pellet containing spherulites.

3. An area in which fresh waters containing high concentrations of carbonate ion flow into shallow sea water might reproduce the laboratory conditions for the chemical precipitation of calcareous ooliths. Such an environment does not appear to be responsible for any large present day deposits of ooliths.

4. Based on the laboratory behavior, environments where sulfate-reducing bacteria might be important in the origin of calcareous ooliths should be characterized by deficiency of oxygen, increased pH, and presence of hydrogen sulfide or sulfide salts. Such environments might be highly localized.

5. The presence of magnesium ion in sea water caused the calcium carbonate to precipitate as aragonite rather than calcite.

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JUNE, 1956

AN APPLICATION OF THE THEORY OF SEDIMENT TRANSPORT BY TURBIDITY CURRENTS TO THE DREDGING OF NAVIGABLE CHANNELS

JOHN S. BRADLEY
Institute of Marine Science, The University of Texas, Port Aransas, Texas

ABSTRACT

By inducing artificial turbidity currents to transport the sediments of obstructing bars into deeper water, the natural phenomenon of sediment transport by turbidity currents may be applied to the dredging of navigable channels. The method may be used provided that sufficient slope is present to allow removal of the sediment by currents, that the sediments are of a type which can form turbidity flows, and that equipment is available for mixing the sediment and water. No accurate cost analysis is presently available.

INTRODUCTION

It is here suggested that the natural phenomenon of sediment transport by turbidity currents may be adaptable to the dredging of navigable channels. The principle is to induce artificial turbidity currents to transport the sediments of obstructing bars or flats into deeper water. Turbidity currents would undoubtedly transport the sediment if equipment can be designed to mix the sediment and water, thereby forming the current.

Turbidity currents are known to occur in lakes and reservoirs (Grover and Howard, 1938) and there is evidence of their occurrence in the sea (Heezen and Ewing, 1952). These currents are thought to be capable of eroding submarine canyons (Daly, 1936; Kuenen, 1937); of transporting sediment great distances in the sea (Stetson and Smith, 1938); of transporting coarse sediment far to sea (Shepard, 1951); of transferring shallow water foraminifera into deep water environments (Phleger, 1951); and of producing graded bedding (Kuenen and Migliorini, 1950). No one, to my knowledge, has suggested that this great natural force be harnessed to work for man.

THEORETICAL ASPECTS

Density flow is caused by the action of gravity upon a fluid which has a greater density than that of the enclosing fluid. The resulting movement is termed a density current. The differential density may result from temperature differences or differences of concentration of solute. If the difference in density is caused by material suspended in the fluid, the resulting movement is called a suspension current or a turbidity current. A density or turbidity current will sink through the enclosing fluid and will move down slope along the bottom if the bottom is not level.

The density difference required to initiate flow is given as .0001 gm/cc relative to unmixed lake water (Bell, 1947). Menard and Ludwick (1951) suggested that the effective density required to initiate flow in the sea would be from .0001 to .001 gm/cc. This is equivalent to .1 to 1 gm/L (Bouyoucos hydrometer units) or approximately 100 to 1000 parts per million (by weight) of suspended material.

The slope required for lateral (downslope) movement is given as less than 5 feet per mile in Lake Mead (Gould, 1951). The status of present knowledge indicates that turbidity currents are capable of transporting fine sediments for great distances even on very gentle slopes. To transport coarser sediments, such as medium to coarse sands, a higher velocity, thus greater slope, or a denser

current of the same velocity are required. The limits of slope, density, and grain size distribution necessary for sediment transport have not been measured.

In nature, turbidity currents may be formed by the introduction of sediment into the ocean, by agitation of the sea stirring up the bottom, and by mass movement (slides) of the bottom (Menard and Ludwick, 1951). A combination of stirring the bottom and initiating mass movement to induce such flows artificially appears promising. Sediment movement could be initiated along a relatively narrow trench by mixing the sediment with water to form a turbid flow. Additional sediment would be moved by slides into the trench, which would tend to form more turbidity currents. Sufficient slope of the bottom must be present to permit turbidity flow to remove the sediment. The initial cut would be at the seaward point at which the slope was sufficient to maintain velocity of the turbidity current so that deposition would not occur. This required slope would be maintained in the trench as it is progressively cut landward. The net effect would be a channel of required depth (25–40 feet) in the harbor (or near the end of the jetties), sloping evenly seaward to a point greater than the channel slope. The theory appears valid. The question arises as to whether the sediment can be efficiently mixed with water to form turbidity currents.

In experimental studies (Kuenen and Migliorini, 1950) great care is taken to mix the sediment and water into a homogeneous slurry. Menard and Ludwick (1951) in discussing the formation of turbidity currents by mud slumping, note that stirring somewhat consolidated mud in water results in some of the mud becoming suspended but most of the mud remains fragmental. They further note that their model makes no accounting of time or of distance moved by the sediments and that a steady churning might eventually produce a high density turbidity current. Complete mobilization of the sediment in a relatively short time would be necessary because turbid water would almost immediately begin to flow from the mixing area. This effect might winnow the deposit, leaving coarse sediments behind if the entire sediment mass were not completely mixed during the period before flow is initiated. This period might be effectively lengthened by using the mixing equipment in tandem. It is seen that a primary requirement for use of the proposed method is that the sediment involved must be capable of being readily mixed with water.*

EQUIPMENT

The application of turbidity current theory to the dredging of channels depends upon the ability to mix all of the sediment sufficiently to allow the resulting turbidity current to carry it away. Several devices now in use, or modified from their present use, might be adapted to this problem.

In relatively shallow water the standard suction dredge could be made to stir up the bottom by merely reversing the water flow. This method has been used in Wilmington and Savannah Harbors, but the tidal ebb current, rather than turbidity currents, was utilized to remove the suspension (Blackman, 1951). The mixing could be made more effective by reversing the water flow of a standard rotary hoe-suction dredge. Various types of jetting might be used with probes or jet piles driven along the channel or with a perforated pipeline laid along the channel. The use of explosives to induce currents has not been satisfactory (Shepard, 1951), probably because of insufficient mixing of sediment with water.

When dredging in deeper water, some simple, easily managed equipment would be required. Perhaps a combination jet and plow system would give adequate breaking and mixing. A rooter or gang plow (or combination) with high velocity water jets could be designed so that it would be adjustable for varying sedi-

* Refer to discussion which follows this paper. Editor.

ment types. The jet-plow would be towed by a tug boat and the water pumps could be on the tug, on an auxiliary vessel, or on the plow. The use of submersible pumps mounted on the plow would allow the use of only two cables, a towing cable and a power cable. This arrangement would avoid the clumsiness of water hoses to surface pumps. An additional advantage of submerged pumps would be that the mixing water would be cold, saline, bottom water which would form a denser current than warmer surface water. The size of the gang plow would be dependent on the available horsepower of the tug.

A perforated pipeline lying along the center line of the channel might be used to jet a trench and, if needed, as a guide for a plow sled. Water pumped through the pipe would jet mix the sediment thrown up by the plow. Some method of controlling the number and spacing of nozzles along the pipe would be required. After digging the original channel, the pipe could be left in place for channel maintenance.

In use, the jet-plow or plow sled would be towed along the center line, starting at the seaward end of the channel and progressing landward. The device would be repeatedly towed along the channel line until the project depth was reached. Slump from the sides into the trench would augment the induced turbidity currents until a stable side angle was obtained. Once the turbidity current was formed, it would remove all the suspended sediment seaward down the slope. If turbidity currents can erode, which is still a debatable question, the induced currents might tend to become self-sustaining and erosive in the lower reaches of the channel.

DISCUSSION

If equipment can be designed to mix the sediment and water, and if the resulting turbidity current can remove the sediment, the question then arises as to whether the process would be economically feasible. At this point no answer can be given, but some of the factors involved in an economic evaluation can be discussed.

An initial expense would be for experimental studies to determine slopes required for current flow for various types of sediment, to determine the relative density difference required to initiate turbidity flow, and to examine various types of equipment and their efficiency. These studies would actually determine the physical feasibility of the process.

After the initial experimental phase, a capital investment would be required to build the prototype equipment. At this point, comparison of costs with those of standard equipment becomes valuable. The tug-jet-plow unit would probably be less expensive than a hopper dredge unit. It would be smaller for comparable horsepower, and would be much simpler mechanically. In operation, the crew and running expense would also be less for the plow unit. No estimate can be made for the jet pipeline equipment.

As a channel dug by the turbidity process would usually be much longer than a standard dredged channel, the preliminary coring and sampling of the right-of-way would be correspondingly more expensive. The amount of sediment moved would be much greater, but the relative expense of moving the sediment cannot be accurately predicted because the effectiveness (efficiency) of both the plow unit and natural slump in forming turbidity currents is not known. From experiment the depth of material moved by each pass of the plow might be predicted. Also the percent efficiency of the slump into the channel might be predicted and this would allow calculation of additional passes required to mobilize the remainder of slumped material. These two predictions would permit estimation of the number of passes required for a given channel and would thereby give the actual dredging expense.

In maintaining the already dug channel, the jet-plow would probably be

cheaper. A few passes in the unconsolidated muds should clear the channel. Periodic pumping of water through the perforated pipeline should keep the channel clear and would probably provide the cheapest maintenance of the three methods. With a standard dredge, the expense of maintaining the channel is the same as for the original dredging. There is the possibility that the long turbidity current channel, once dug, would tend to become self-sustaining. Also, if the sediment load from a river mouth into the channel became large enough (as at flood stage), the river turbidity would induce natural currents (Menard and Ludwick, 1951). There is also the possibility that turbidity currents can erode and that once initiated the channel might be self-forming and self-sustaining. The erosive force of the current is probably a function of the current velocity, i.e., of the bottom slope for a given turbidity. A channel could be planned with a minimum slope to allow the stirred up sediment to be removed from the area or with a maximum slope to give current velocities high enough to erode a channel. Experiments would be required to validate the latter hypothesis. It is probable that a slope which would give currents with a high enough velocity to erode would require a channel of uneconomic length.

To apply this process to a specific area, a careful evaluation of available channel routes would be required. Shell reefs, hard pan, and consolidated sediments should be avoided where possible. A route through smaller grain size sediments would be desirable, but pure clays have a tendency to consolidate and to be "waterproof." A friable silty clay or sandy silt would be an ideal sediment in which to induce turbidity currents. The maximum size of sediment particles which could be transported would be determined by the slope available and by the percentage of fines in the coarse sediment. A clean, coarse sand would not form an effective current on a shallow slope, but the same sand could be transported if substantial amounts of clay or silt were present. Coarse material would tend to lag and would be reworked by the plow in the channel. The amount of coarse material (not transportable) must be small or it will pave the channel preventing the plow from stirring up additional sediments.

In choosing the channel site, it would be wise to evaluate not only the length of the channel and the suitability of the sediments, but also the factors of prevailing winds and currents. Whenever possible the natural currents should be used to augment the action of the turbidity currents. Also, Price (1952) states the proper orientation of a channel will greatly reduce sedimentation in the channel and, thereby, the cost of maintaining the channel.

It is possible that the original dredging costs of the several methods are comparable. There are indications that the maintenance costs might be less for the plowed channel. Great savings could be realized by the utilization of turbidity currents in those areas which require continuous dredging or jetty extensions to maintain channel depth over the bar.

CONCLUSION

It is concluded (1) that sediment can be transported by turbidity currents and (2) that turbidity currents may be artificially induced by mixing bottom sediment and water.

These facts would permit the use of turbidity currents for the dredging of navigable channels provided: (1) the sediment is of a type which can form turbidity flows, (2) sufficient slope is present to allow removal of sediment by the currents, and (3) equipment is available for mixing the sediment and water.

The economic feasibility of the process is in doubt until experiments show the required slope, the required density of suspension, and whether or not the cost of operating equipment to mix the bot-

tom sediment is within reason. Further, the feasibility of each application would depend on the geographic, geologic, and oceanographic setting of the chosen area.

It now appears that there is the possibility that this powerful natural phenomenon may be harnessed to do man's work.

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DISCUSSION

Publication of the foregoing paper by John S. Bradley is a departure from the usual policy of this Journal in that the paper contains speculations and suggestions which are not supported by observed factual data or by experience in technological practice. Because of the great interest in turbidity currents which has been shown by sedimentary petrologists in recent years, these suggestions of a possible practical application of the phenomenon and plea for further investigation and development are considered to be appropriate for publication.

There seems to be little room for doubt that after a suspension of sediment is produced, it will flow a considerable distance on a slight gradient. An example of this was observed in a reservoir, Lake Lee, North Carolina, in 1938. The turbid runoff from a heavy shower in the watershed entered the reservoir, turned under the lighter lake water, and flowed 8000 feet to the dam on a bottom gradient of 7 feet per mile. A detailed survey of the reservoir deposits and a study of their grain sizes suggest that most of the sediment in that lake was deposited from turbidity currents (Hough, 1939).

The manuscript of Bradley's paper was referred to the Department of Civil Engineering, University of Illinois, for comments. Professor Don U. Deere, geological engineer, called attention to Bradley's statement, "It is seen that a primary requirement for use of the proposed method is that the sediment involved must be capable of being readily

mixed with water," as the key to the proposed operation, and stated, "Many of the harbor sediments which I have seen have possessed cohesion to the extent that they are very difficult to mix into a slurry. Plowing or agitating with a jet would only break them up into slugs of mud." Professor John C. Guillou of the Hydraulic Engineering Laboratory commented, in part, as follows: "If the sediments are consolidated [compacted] to an appreciable degree, there is no question in my mind but that the author's plows and dredges will not create adequate density currents without auxiliary grinding. . . . It is easy to visualize a seaward trench, as described by the author, that represents in excess of 5000 to 10,000 cubic feet of material per lineal foot. Even if the material is unconsolidated and very fine, this volume requires at least an equivalent amount of transport water. This water may be pumped or, in the author's expectancy, a part of it will be obtained during the agitation of the bottom sediments. In any event, a tremendous horsepower requirement is obvious. . . . The author presents in general fashion an exceedingly interesting solution. However, there is no doubt but that a great deal more knowledge is required before his proposal will be economically feasible."

Dr. Bradley, in his paper, has indicated that he is aware of these problems.

J. L. HOUGH

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The following was received on May 6, 1956 from Dr. Bradley:

"It may be of interest to you to hear that I recently ran across an old reference (Corthell, E. L., 1881) which indicates that the stirring up of bar sediments is not new. On page 17 Corthell reports 'Attempts were made, as early as 1726, to deepen the channel . . . by dragging iron harrows over the bars. . . . ' And on page 18, 'In 1868–69 the Government constructed a steam propeller dredge, at the cost of $350,000. The propeller stirred up the mud at the bottom and threw it to the surface by means of a deflector behind the propellor, the object being to have it carried away by the currents. A second boat of similar plan was built soon after. These boats were in almost constant use for three years. . . . The results obtained did not warrant them (the engineers) in estimating that a greater depth than 18 feet could be maintained by the dredge boats.' I wonder what would have happened if they had worked inland from the face rather than seaward on the top of the bar. At least this reference indicates that the sediments are readily mixed with water. Fisk, et al., (1954, figs. 9 and 12) also indicate that the sediments at the mouths of the passes are suitable for mixing."

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FIGS. 1–3, JUNE, 1956

CLAY MINERALS FROM THE RÖT MEMBER OF THE TRIASSIC NEAR GÖTTINGEN, GERMANY

FRIEDRICH LIPPMANN
University of Illinois, Urbana, Illinois[1]

ABSTRACT

This paper includes a description of the clay mineral composition of the Röt member of the Triassic near Göttingen, Germany. The important constituent is a "swelling chlorite" with a regular mixed layer structure for which the name "corrensite" was suggested in an earlier paper. A considerable part of the paper is devoted to the specific properties of corrensite, particularly after treatment with several exchangeable cations.

The purpose of the present paper is to report on another occurrence in Germany of an interesting clay mineral which consists of a regular interstratification of chlorite and vermiculite ("swelling chlorite") with the ratio 1:1, and for which the author proposed the name "corrensite" in an earlier paper (Lippmann, 1954). Although the new finding was made in a lithology similar to the first one, a typical "red bed association," it comes from a different level within the Triassic than the previous ones (Lippmann, 1954; Jasmund, 1954). It therefore seems advisable to give a brief outline of the stratigraphy of the Triassic around Göttingen.

The German Triassic is commonly subdivided into the three classical formations: Buntsandstein, Muschelkalk and Keuper. The Buntsandstein is named from its morphologically most important middle member alone, which consists of massive, often cross-bedded, light-colored to dark-red sandstones (thickness, 150–500 m). The lower Buntsandstein actually is made up of red shales with interstratified sandstones. The upper Buntsandstein also contains very little sandstone and is a series consisting mostly of shales, some sandstones, and some siltstones. Its color is generally red; therefore, this member is often called "Röt" as well as "Oberer Buntsandstein." Sometimes greenish-gray shales and beds of gypsum of apparently lenticular habit occur. In places the latter are slowly being dissolved in the subsurface which from time to time causes collapses. These collapses are manifested by the formation of sink-like pits and other solution subsidence phenomena. On the surface the shales disintegrate very readily and areas of Röt are commonly covered with cultivated fields and pastures of moderately good quality. Extensive outcrops being comparatively scarce, it has been almost impossible to establish detailed sections of the "Röt", the thickness of which has been estimated to be 80–150 m around Göttingen (Stille and Lotze, 1933). The major part of the Röt is probably of non-marine origin like the lower membe. Only in the topmost few meters have, marine fossils been reported (as a prelude to the marine conditions of the superjacent Muschelkalk). Occasional occurrences of rock salt in the subsurface and frequent occurrences of rock salt pseudomorphs in the siltstones in addition to the gypsum beds are indicative of the saline character of the Röt. It can be visualized that the Röt was deposited in a continental salt lake and salt flat environment. The Röt is overlain by the Muschelkalk formation which is about 200 m thick and consists

[1] Present address: Sedimentpetrographisches Institut, Lotzestrasse 13, Göttingen, Germany.

of rather impure marine limestones with a few horizons of pure limestones. The middle member is characterized by an evaporite facies with gypsum and, in certain places in the subsurface, with rock salt. The overlying Keuper formation consists in its lower member (30–50 m thickness) of shales, dolomites, and sandstones with occasional coal stringers. The most important member of the Keuper is the middle one, sometimes called "Gipskeuper" in allusion to the frequent occurrence of gypsum beds in it. Except for the occurrence of some sandstone, the lithology of the Middle Keuper, consisting mainly of red and sometimes greenish-gray shales and marls, has a striking resemblance to that of the Röt. It was in the Middle Keuper that the author first found corrensite in Southern Germany (Lippmann, 1954), and later it has been reported by Jasmund (1954) from the brick clay pit in the Middle Keuper at Friedland near Göttingen. The English occurrences reported by Honeyborne (1951) are in the "Keuper Marl" which seems to be quite similar to the German Middle Keuper both in lithology and stratigraphic position.

THE SAMPLE LOCALITY

Owing to the generally poor outcrop conditions of the Röt, sampling depends to a great extent on occasional temporary outcrops caused by construction. The present samples come from the escarpment of the north eastern-most prominence, called Hünstollen, of the Göttingen Muschelkalk Plateau. The escarpment is due to the greater resistance of Muschelkalk-limestones overlying the Röt. A newly cleared timber-road cut into the Röt and winding around the Hünstollen yielded exposures which were comparatively unaltered and undisturbed by landslides. The roadcut on the east-southeastern flank of the Hünstollen shows the following section in the place where the samples were taken, which may be estimated 10–20 m below the bottom of the Muschelkalk.

Thickness (cm)	*Soil*
130	very thin-bedded interstratification of red and gray shale with some siltstone laminae; highly dolomitic, sample #4
2–3	greenish-gray, hard siltstone
110	red argillaceous shale, apparently homogeneous, slightly carbonate-bearing, sample #3
2–3	greenish-gray, hard siltstone
50	sandy, red shale, highly calcitic on top, sample #2; slightly carbonate-bearing on the bottom, sample #1 bottom of outcrop

Two other samples from the recently reopened pit of the brick plant "Hölle" were provided by the kindness of Prof. E. Ackermann, Göttingen. The pit is situated at the foot of the Hünstollen on the border of the forest, about 70–80 m lower than the previous locality. One sample is a greenish-gray shale (sample A), the other one is a red shale (sample B). Both are free from carbonate. Sample B is 60 cm from the bottom of the pit, sample A about 100 cm.

DIFFERENTIAL THERMAL ANALYSIS

DTA curves were taken from the bulk samples #1–4 both in the raw state and after the carbonates has been dissolved with diluted hydrochloric acid. The DTA apparatus used was essentially the same as that described by Grim and Rowland (1942). The curves of the carbonate-free clay are quite uniform except for the intensities of the peaks, which are somewhat variable owing to quantitative differences. A low temperature endothermic peak is present around 100° C or slightly above. Between 500° and 600° C there is an assymetric endothermic inflection with the peak between 610° and 620°. An endothermic peak at about 830° C, which has about the same amplitude but is narrower than that above 600°, is followed immediately by an exothermic maximum at about 890°. The character of the DTA traces is the same as that of the "Keuperton" from Zaiserweiher and shows that a chloritic mineral is present as a chief component. Judging from the amplitudes of the peaks, the

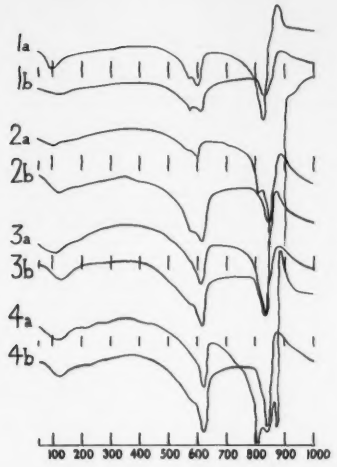

FIG. 1.—DTA traces of samples 1 to 4. Raw samples are marked *a*. The traces which were run after dissolving the carbonates with dilute hydrochloric acid are marked *b*. Temperature scale is in degrees centigrade.

amount of the chloritic mineral, later shown to be mainly corrensite, decreases in the following sequence in the carbonate-free samples: *4, 3, 2, 1*. In the trace of the raw sample #2 there is a very intense endothermic peak present between 830° and 900° C in addition to the features of the chloritic mineral, which is indicative of a considerable amount of calcite. Likewise, with the raw sample #4 there are two additional endothermic peaks between 800° and 900° C, one below the high temperature endothermic peak of the chloritic mineral and the other above, which indicate the presence of dolomite. In the raw samples #1 and *#3 the 830°* peaks are larger than in the acid treated samples, showing that the reaction of some carbonate is superimposed. On the low temperature flanks of the 600° peaks reactions of quartz are superimposed, the intensity of which decreases from sample #1 through #4 for the acid treated samples and less conspicuously but in the same sequence for the raw ones.

GRAIN SIZE SEPARATION

The samples were dispersed in 0.01 N ammonia and grain size fractions were separated by repeated sedimentation by means of Atterberg cylinders. The quantitative results are as follows:

Fraction	Sample #1	#2	#3	#4
	Weight % for 110° C			
<2μ	18%	9%	9%	24%
2–6.3	15	10	8	21
6.3–20	18	42	14	25
20–63	9	34	14	30
>63	40	5	54	
Water loss at 100° C	3.7% (air dry)	7.2%	8.8%	7.5%

These values of the grain size analyses are of no great importance since the shales are compacted to such an extent that it is impossible to disintegrate them in the laboratory to their ultimate grain size. It can be seen that the fractions larger than 63 μ consist largely of shale fragments, especially in sample *#3*, and one may suspect that also in the other fraction above *2μ* considerable amounts of aggregates are present. From the samples A and B only the fractions *<2μ* were separated for the X-ray diffraction analysis.

X-RAY DETERMINATION OF MINERAL COMPOSITION

The most important part of the work was the examination of the finest grain size fractions by X-ray diffraction. Besides the fraction *<2 μ* the fractions 2–6.3 μ were checked also. Spectrometer traces were obtained by a G-E XRD3 recording diffraction unit from orientated flakes which were prepared by evaporation of rather thick clay suspensions on microscope slides (Johns, Grim, and Bradley, 1954). For obtaining additional information on non-clay minerals and on the non-basal lines of the clay minerals,

powder patterns were prepared with the film method. The following minerals were determined: corrensite, chlorite, illite, quartz, hematite, dolomite, and calcite.

Corrensite

The presence of corrensite is manifested by the series of basal spacings 29 Å, 14.5 Å, 7.2 Å, 4.79 Å, and 3.57 Å in air dry specimens and by the regular shift of this series on soaking with polar organic liquids. Ethylene glycol, for example, yields the series: 31 Å, 15.5 Å, 7.75 Å, 5.15 Å, etc. By the glycol treatment it is revealed that a part of the intensities of the corrensite lines, especially of the higher orders, are to be attributed to non-swelling chlorite as a discrete phase. This chlorite has a somewhat lower spacing then the unswollen corrensite: 14.2 Å, 7.13 Å, 4.77 Å, and 3.56 Å. Consequently, the higher orders of the untreated corrensite seem to have spacings lower than expected calculating from the 14.5 Å line, especially if they are measured by the positions of their peaks. The agreement is better if the positions of the corrensite lines are determined as the center of the base of each line. This may be exemplified with the line at about 7 Å. The untreated case yields a distinctly assymmetrical line with the peak at 7.13 Å and the center of the base at 7.20 Å. On treatment with glycol, part of the line shifts to 7.75 Å and a sharp symmetrical line stays at 7.13 Å. The same is true to some extent also for the other higher orders, but it may not be seen as easily owing to the contiguity of the illite lines. The low-angle spacing may not be determined very accurately since it only forms a shoulder in the steep descent of the background intensity, but the shift on a glycol saturation is clear in most cases. It is, therefore, justified to calculate this spacing more exactly from its second order. The corrensite is trioctahedral, for it is certain that from the two (060) spacings at 1.50 Å and 1.54 Å obtained from films, the first one is to be attributed to illite so that the 1.54 Å line remains for corrensite (and chlorite). The relative abundance of corrensite judged by the intensity of the 14.5 Å line in comparison to the first order of illite increases in the $<2\ \mu$ fractions of the samples as follows: 4, 3, 1, 2, A, B.

In the stratigraphically lowest samples A and B corrensite plus chlorite are only minor components compared with illite, which forms the bulk. Glycol treatment shows that in sample A the 14.5 Å line shifts entirely to 15.5 Å whereas in Sample B about a half of its intensity stays 14.5 Å. Thus A has more corrensite and B has more chlorite.

Generally the fractions 2–6.3 μ contain less corrensite than $<2\ \mu$.

A detailed description of the effect of various treatments of the corrensite from sample 4 will be given in a later paragraph.

Illite

The series of basal spacings of illite can be observed in all samples. The presence of the (060) line at 1.50 Å suggests that the bulk is dioctahedral. Except for the samples A and B of which illite is the predominant constituent, illite and corrensite are of about the same quantitative importance, sample 4 having least illite. The decrease of illite in favor of non-clay minerals towards the fractions 2–6.3 μ does not seem to be as important as that of corrensite.

Hematite

The red color of all samples except A strongly suggests the presence of hematite. This could be proved by the strongest diffraction lines of hematite 2.69 Å, 2.51 Å, 1.83 Å, 1.69 Å, and 1.45 Å, which appear with weak to very weak intensities on the powder films of the fractions $<2\ \mu$ and 2–6.3 μ.

Quartz

Quartz is present in all samples. In the fractions $<2\ \mu$, traces of it may be recognized by spots of the strongest quartz line 3.35 Å superimposed on the 3.33 Å

(third order) illite line. In the fractions 2–6.3 μ, dotted quartz lines are present at 4.25 Å, 3.35 Å, and 1.81 Å.

Carbonates

In the fractions <2 μ no carbonates can be detected. In the fractions 2–6.3 μ of the first four samples, the most prominent carbonate is dolomite indicated by its strongest lines at 3.69 Å, 2.88 Å, and 2.19 Å, which are dotted on films taken without specimen rotation. The strongest calcite line at 3.03 Å comes out just visibly. It is most coarsely dotted in sample 2 (2–6.3 μ), which is in accordance with the high calcite content judged from the DTA curve of the raw sample.

Faint dotted lines in 2–6.3 μ at about 3.23 Å may be interpreted as traces of feldspars.

Experiments with Corrensite

Since sample #4 is especially rich in corrensite it offered a good opportunity to study various properties in detail. The most detailed diffraction data on corrensite have been given by Bradley and Weaver (1955) who had a corrensite sample available which was extremely regularly crystallized and did not contain any illite so that these authors could observe all basal orders, some of which in the present case are masked by illite lines. They could determine a relatively high base exchange capacity (40 me/100 g) on their almost pure sample. It was, therefore, interesting to study the influence of various cation saturations on the corrensite. Parts of the <2 μ fractions of sample #4 were saturated with Na, K, NH_4, Mg, Ca, and Ba by treating the clay with excess 1N solution of the respective salts. The supensions were vigorously shaken and allowed to stand for 24 hours. This was repeated four times using fresh salt solution after the supernatant liquid had been decanted after each soaking period of 24 hours. The clays were then carefully washed until flocculation was decreased as far as possible. Flocculation could not be inhibited entirely even by long-lasting washing in the Ba-, Ca-, and Mg-clays, and the NH_4-clay and to some extent the K-clays, also showed flocculation after about one day's time. Thus only the Na-clay yields an entirely non-flocculating suspension. Oriented slides were prepared from these washed suspensions which were studied after various treatments.

Air Dry State

Of all the cations, calcium gives the best integral series of basal spacings in air-dry state (see table 1). The agreement with the values of Bradley and Weaver is satisfactory if the lines coinciding with chlorite lines are measured by their centers and not by their peaks as previously stated. The spacings of corrensite are sufficiently close to rational submultiples of 29.2 Å as is shown by the calculated 001 spacings from each order. The 003 and the 007 spacings of Bradley and Weaver could not be found, the former coinciding with the first order of illite and the latter being very weak with Bradley and Weaver also.

Whereas the data with calcium saturation can be interpreted in terms of regular interlayering of chlorite and vermiculite units in the ratio 1:1, the influence of the other cations in air-dry state may only be explained if one assumes some irregular interstratification. According to their effect the cations may be classed into two groups, magnesium on one side, and sodium, potassium, ammonium, and barium on the other. Both groups tend to make those lines in which chlorite and corrensite spacings coincide (near 7.1 Å, 4.7 Å, and 3.5 Å) more symmetrical than they are with calcium saturation, and the spacings determined from the peak and the center of the base of these lines come to close agreement. In the case of magnesium these lines are stronger than with the other group of cations. This is probably due to some kind of reorganization by intake of magnesium of the

brucite sheets by the vermiculite units into which magnesium ions fit best. This way the vermiculite units become more similar to the chlorite units, and the air dry Mg-corrensite comes to resemble the non-swelling chlorite in its higher basal orders. That this reorganization of the vermiculite units does not happen in quite an orderly way may be seen from the slight deviation of the measured spacing of the 14.6 Å line compared with the value of 14.2 Å which one should expect from the higher orders with 7.13 Å, 4.76 Å, 3.56 Å, and 2.86 Å.

The other cations (Na, K, NH_4, Ba) reduce the intensities of these lines considerably. They appear to be no stronger than after glycol treatment, in which case they are caused only by the amount of non-swelling chlorite present in the sample. This is accompanied by the appearance of a line of medium intensity at about 5.3 Å, which forms a distinct shoulder on the low-angle side of the 5 Å illite line and with sodium a weak, broad band between 3.7 Å and 3.8 Å. Both these diffraction maxima do not represent submultiples of any spacing

TABLE 1.—*Diffraction data for sample #4 <2μ, Ca-saturated, air-dry: compared to Bradley and Weaver's data, air-dry*

Ca-clay				Bradley and Weaver		
Intensity Remarks	dÅ	Identification	d 001 Calcul.	dÅ	Corrected Intensity	
shoulder	29.5	001	29.5	29	+3.8	
sss	14.6	002	29.2	14.6	−9.2	
ss	10.0	(003) and illite		9.93	+4.0	
middle s	7.25	004	29.0	7.30	+6.5	
peak	7.13	chlorite				
ww	5.86	005	29.3	5.90	+2.7	
s	5.00	illite				
s	4.87	006	29.2	4.90	+8.6	
		007		4.17	+2.2	
middle s	3.59	008	28.7	3.63	+7.8	
peak	3.55	chlorite				
ss	3.33	illite				
shoulder on 3.33 ww	3.24	009	29.2	3.27	+3.0	
m	2.93	0010	29.3	2.92	−5.9	
m	2.00	illite				

TABLE 2.—*Diffraction data for sample #4, <2μ, air-dry, saturated with various cations*

Na		K		NH_4		Mg		Ca		Ba	
Intens.	dÅ	Intens.	dÅ	Intens.	dÅ	Intens.	dÅ	Intens.	dÅ	Intens.	dÅ
shoulder	29	shoulder	29	shoulder	29?	shoulder	29	shoulder	29.5	shoulder	29
SSS	14.2	SSS	14.5	SSS	14.0	SSS	14.5	SSS	14.6	SSS	14.2
SS	10.0	SS	10.0	SS	10.0	SS	10.0	SS	10.0	illite SS	10.0
				w	9.0					ww?	9.0
middle m	7.18	middle m	7.18	middle m	7.13	middle s	7.16	middle s	7.25	middle m	7.13
peak	7.13	peak	7.13	peak	7.13	peak	7.13	peak	7.13	peak	7.13
shoulder w	5.3	—	—	shoulder w	5.3			ww	5.86		
illite s	5.0	illite s	50	s	5.0	illite s	5.0	illite s	5.0	illite m	5.0
m	4.79	m	4.79	m	4.77	s	4.77	s	4.87	w	4.77
w	4.55										
ww	3.67							middle s	3.59	ww	3.67
m	3.56	m	3.56	m	3.56	m	3.56	peak	3.55	w	3.56
illite ss	3.33	illite ss	3.33	illite ss	3.33	illite ss	3.33	illite ss	3.33	illite m	3.33
broad w	2.93	broad w	2.92	very broad ww	2.95	w	2.88	shoulder ww	3.24	ww	2.98–2.83
								w	2.93		
illite w	2.00	illite w	2.00	illite w	2.00	illite weak	2.00	w	2.00	w	2.00

between 28 and 29 Å. Moreover, the 14 Å lines indicate distinctly lower spacings than with Mg and Ca, 14.2 Å for Na, K, and Ba and 14.0 Å for NH_4.

Ammonium is remarkable in that a weak line, exhibited at 9.02 Å. may be regarded as the third order of the 28 Å line although it is not exactly one third of 28.

All these features suggest that the action of the cations, with the exception of Ca and Mg, may be interpreted in the following way. These cations are not as tightly hydrated as Ca and Mg ions with their higher charge and/or smaller ionic radius. Therefore, they are not able to stabilize the brucite sheets of the regularly interstratified vermiculite units as do Mg and Ca. Thus, at least part of the vermiculite units collapse from their original size of about 14 Å to about 10 Å. This is an established fact for pure vermiculite, and occurs most easily with NH_4 (Walker, 1951). In our case, not all vermiculite units do collapse because they probably are not uniformly depleted in Mg, and their Mg content should be lower in some units and, what seems to be more important, higher in others than with regular vermiculite since otherwise the corrensite should change its 14 Å with ammonium saturation to about 12 Å, the arithmetic mean of 14 Å for the chlorite units and 10 Å for the collapsed vermiculite units. Stacks of silicate sheets containing collapsed and unaffected vermiculite units at the same time should not exhibit a regular sequence of higher orders. This is found on saturation with the group of cations in consideration. The apparently irrationally spaced line at 5.3 Å might be re-

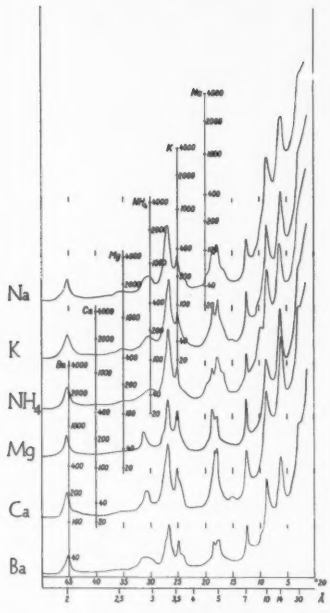

FIG. 2.—X-ray diffraction spectometer traces of sample 4. $<2\ \mu$, after saturation with different cations. Spectrometer: GE-XRD3; radiation: CuKα. Air dry state. Each trace is provided with an intensity scale in counts per second, which is marked with the chemical symbol of the saturation cation like the trace itself.

garded as a higher (5th) order of some spacing between 29 Å and 24 Å, which one might expect to result in irregular partial collapse of the vermiculite units. A weak first-order band in this region might easily escape observation owing to its contiguity with the sharp 29 Å shoulder in the background; the presence of this shoulder shows, moreover, that such collapsed vermiculite layers are not too frequent.

SWELLING WITH POLAR LIQUIDS

Ethyleneglycol

Best diffraction data on swollen corrensite are obtained on soaking the orientated flakes for at least a day in an atmosphere of ethyleneglycol vapor. With all different cation saturations used, equally well-developed series of basal spacings of the glycol—corrensite complex are observed. The only differences exhibited are in the intensities of the whole patterns, including the illite lines, the pattern of the sodium clay, and also to some extent that of the calcium and potassium clay being stronger. This may be easily understood for the case of sodium and potassium since they were found, as stated above, to have the least flocculating effect on the clay, thus allowing a better parallel orientation of the clay flakes. In the case of calcium it could be suggested that these ions are probably more tightly absorbed by corrensite, as may be deduced from the more regular organization of the Ca-corrensite in air-dry state. Therefore, as the suspension on the slide becomes more concentrated in the last stage of evaporation, the amount of ions in solution, although slight with all kinds of cations, might be smallest for calcium, it being more strongly attracted on the interlayer surfaces. Since all cations give the same kind of diffraction data for the glycol-corrensite complex only the data for sodium are given in table 3, because, owing to the great intensity of the sodium pattern, they should be most accurate of all. Moreover, with sodium, the high spacing of 31 Å appears as a real small peak on the trace and not only as a shoulder as with the other cations. All higher orders which have been found by Bradley and Weaver appear, except those which were observed to be very weak by these authors. The third order is covered by the 10 Å of illite. All higher orders are submultiples of the fundamental period of 31 Å within the limits of accuracy.

It may be concluded from these observations that the sequence of the layer units expandable with glycol (A) (vermiculite units) and those which do not expand with glycol (B) (chlorite units)

TABLE 3.—*Diffraction data for sample #4 <2μ, Na saturated, ethylene-glycol complex: compared to Bradley and Weaver's data on their glycol complex*

Na−Clay+Glycol				Bradley and Weaver's Glycol-Complex			
Intens.	dÅ	Identification	001 Calcul.		dÅ	Corrected Intensity	
S	31.5	001	31.5		31	+ 5.0	
SSS	15.6	002	31.2		15.5	−10.0	
SS	10.0	003+ illite			10.2	+ 1.9	
S	7.75	004	31.0		7.7	+ 8.0	
m	7.1	chlorite					
ww?	6.45	005?	34.2		6.2	+ 1.7	
S	5.15	006	30.9		5.12	+ 7.2	
S	5.0	illite					
w	4.74	chlorite					
w	4.45	007	31.2		4.40	+ 5.0	
ww?	3.85	008	30.8		3.84	+ 3.4	
w	3.55	chlorite					
S	3.44	009	31.0		3.44	+ 9.8	
SS	3.33	illite					
		0010			3.08	− 2.0	
w	2.84	0011	31.2			+ 5.8	
w	2.00	illite					

conforms very closely to the pattern . . . ABABABAB . . . .

Other Liquids

In the first place it must be stated that with all other liquids used no change takes place in the diffraction if the sample had only been exposed to the respective vapors. To bring about shifts in the diffraction patterns the specimens had to be entirely soaked so that excess of the liquid was present. This was done with water by using slides on which the suspension was evaporated to a point that it formed so thick a slurry that it could not creep away when the slide was mounted vertically on the spectrometer. The intensity of the spectrometer traces including the illite lines obtained from these wet mounts is rather low. The intensity is lower the more excess of water is present because the water inhibits a perfect orientation of the clay mineral flakes parallel to the slide. For obtaining maximum orientation with excess of water, sets of successive traces were run during the slow spontaneous evaporation of the water on the spectrometer. The point at which no more excess water was present could be checked from the color

of the clay which has a distinctly darker shade when wet. As soon as all the water had evaporated the diffraction diagrams were the same as at 55 percent relative humidity, which means that a change from 55 percent relative humidity up to just below 100 percent does not change the basal spacing of corrensite. The spacings of the water-soaked clay are best observed by the second orders because the low-angle first order is just slightly visible as a shoulder in the background descent. The second order is situated between 15 Å and 16 Å and is considerably broader than it is with air-dry or glycol saturated specimens. A fourth order, present around 8 Å, is a rather very broad band with relatively low intensity. The following table shows the variations with cation saturation. Since other lines present may be attributed either to non-swelling chlorite or illite they are not given.

TABLE 4

Cation	Second Order Å	Fourth Order Å
Na	15.8	8.0
K	15.8	8.0–7.13
NH_4	15.0	8.0–7.13?
Mg	16.0	8.3
Ca	15.8	8.8–7.13
Ba	15.8	?

From the broadness of the diffraction maxima and from the absence of higher orders one may conclude that the water-corrensite complexes are very poorly ordered. The resultant spacings seem to be governed by the kind of cation. The Na and Mg cations which are probably the most hydrated give the largest spacings, and NH_4, which is least hydrated, yields the smallest. Moreover, correlation between degree of hydration of the cation and the orderliness of the complexes is indicated since with Na and Mg the fourth order is best developed and doubtful with NH_4 and Ba.

As organic liquids, glycerol, methyl alcohol, ethyl alcohol, acetone, and acetonitrile were used. They were sprayed on the specimens with an atomizer. This had to be repeated from time to time with the volatile liquids while the orientated slides were mounted in the spectrometer and the traces were being run. The action of methyl alcohol, ethyl alcohol, acetone, and glycerol on the diffraction diagrams gave results which did not depend on whether the cation was Na, Mg, or Ca. NH_4 behaved differently, and K and Ba clays were not examined at all. Methyl alcohol on the Na-, Mg-, and Ca-clays caused broad second order peaks

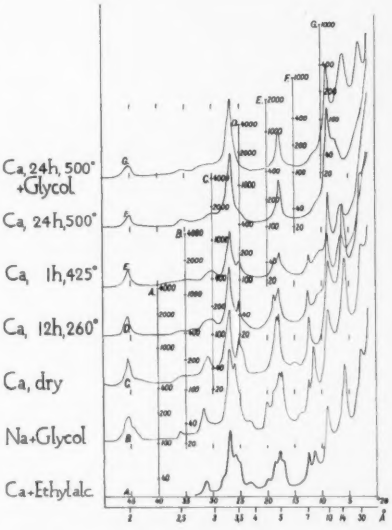

FIG. 3.—X-ray diffraction spectrometer traces of sample 4. <2 μ, after different treatments. Spectrometer: GE-XRD3; radiation: CuKα. A. Ca-clay saturated with ethyl alcohol; B. Na-clay saturated with ethylene glycol; C. Ca-clay, air-dry; D. Ca-clay heated at 260° C for 12 hours; E. Ca-clay heated at 425° C for one hour; F. Ca-clay heated at 500° C for 24 hours; G. Ca-clay heated at 500° C for 24 hours and saturated with ethylene glycol after cooling. The intensity scales (counts per second) are marked with the same capital letters as the traces to which they belong.

at 15.2 Å of strong intensity and a weak fourth order at 7.8 Å. Although the first order reflection is developed as a little peak, the order of the methyl alcohol complex seems to be poor since no higher orders appear beyond the fourth one. The ethyl alcohol complex yields a set of basal spacings which is almost as complete as that for the glycol complex. The following data were obtained: 001: 31 Å (peak!); 002: 15.5 Å; 004: 7.8 Å; 006: 5.12 Å; 007: 4.45 Å; 008: ?3.90 Å (not always detectable); 009: 3.43 Å. Consequently the quality of organization with ethyl alcohol is comparable to that with glycol.

Acetone causes a broad line between 17 Å and 16.4 Å. The fourth order is indicated as a broad band between 9 Å and 7.2 Å. Thus, regularity of the swelling is poorer than with water.

Acetonitrile was used because it has been reported to form complexes with montmorillonite forming trimolecular layers. Its complexes formed with corrensite seem to depend to some extent on the cation:

	Second Order	*Fourth Order*
Na	16.6 Å	8.5 Å
Mg	17.0 Å	8.4 Å
Ca	15.2 Å	7.8 Å

Acetonitrile gives a reaction also with the NH_4-clay, with which the aforementioned organic liquids have no perceptible effect. Broad reflections which are not well reproducible were observed; for example: 14.7 Å, 16 Å, 15.5 Å.

Glycerol treatment yields extended spacings with all cations, the most prominent lines being at 16.4 Å and 8.18 Å. It is very difficult to obtain good information on the higher orders with glycerol, because the patterns obtained are rather weak. It seems to be difficult to add the right amount of glycerol so that it is usually in excess and disturbs the quality of parallel orientation in the preparation.

THE EFFECT OF HEAT ON CORRENSITE

The oriented specimens of the clay were heated to various temperatures up to 550° C. Spectrometer traces were run immediately after the slides had been removed from the furnace and had cooled sufficiently for handling. On heating at 260° for one hour, and also for twelve hours, the second order becomes less intense and broadens, the peak being at 14 Å for the earth-alkalies and apparently a little lower (13.8 Å) for the alkalies. A broad third order is shown between 8 Å and 9 Å, which is comparable to that of the air-dry NH_4-clay. Heating at 120° for about one day has essentially the same effect as the treatment at 260°. It was found that the clays heated at 260° are still able to form extended complexes with ethylene-glycol as the air-dry samples do.

Heating at 425° for an hour yields broad spacings at about 13.8 Å for the earth alkalies and 13.5 Å for alkalies, the broad band between 8 Å and 9 Å still being visible. Heating at 500° C gives about 13.0 Å for the alkalies, the earth-alkalies are not changed, and the third order band disappears with the sodium clay. At 550°, sodium shifts to about 12 Å, the other clays are at 13 Å.

After heating at 500° for about one day very broad bands with maxima at about 12 Å are indicated as shoulders on the low angle side of the likewise broadened 10 Å lines of the illite; besides that only the other illite lines are left in the diagrams. These shoulders are best visible for the Ba-, Ca- and K-clays, less visible for the Mg-clay, whereas with the Na-clay an asymmetrical broadening to lower angles of the 10 Å line of illite is the only feature to be observed. It is very interesting that these clays after having been heated at 500° for 24 hours are still able to form complexes with ethyleneglycol when exposed to its vapors for one day. The sodium clay shows only one broad peak at 13.2 Å. With all other cations broad peaks are present at 29.5 Å and 14.7 Å. No higher orders are present.

The diffraction data from the heating experiments are poor in comparison to those of Bradley and Weaver who ob-

tained a fundamental period of 24 Å with a series of comparatively sharp higher order after heating their specimen at 550° for 2 hours. The only similarity which the present results have to theirs is the slow shift of the second order band to 12 Å on prolonged heating, from which a very disordered 24 Å period may be deduced.

The vermiculite layers in the material of Bradley and Weaver seem to collapse readily from about 14 Å to 10 Å on heating, thus by the regular alternation with 14 Å chlorite units the 24 Å periodicity results. The sluggishness of the conversion in our case and the resulting diffraction data confirm the picture which had already been conjectured above from the behavior of the corrensite in air-dry state with different cation saturation and from the uniformity of the ethylene-glycol complexes. The vermiculite layers, although regularly alternating with chlorite layers, are not uniform among themselves. At least part of them contain more magnesium than is compatible for an easy breakdown to 10 Å. Others, especially in the alkali-treated instances, may contain less magnesium. Thus a regular sequence with a 24 Å periodicity is not reached but probably a sequence . . . ABABAB . . . where A may have any spacings between 10 Å and 14 Å, and the B (chlorite) units should have essentially remained unaffected at about 14 Å. The thickness of the A layers could also vary laterally within the same layer.

The expansion with glycol of the material heated at 500° for 24 hours can not be interpreted in great detail since it cannot be decided to what degree the brucite layers of the chlorite units have been dehydrated. But it is certain that the collapsed vermiculite units are responsible for the expansion and that the arrangment of the basic unit still follows the scheme . . . ABABAB . . . to a considerable degree as can be seen from the presence of the band at 29 Å.

SUMMARY OF THE CHARACTER OF CORRENSITE AND DISCUSSION OF ITS POSSIBLE ORIGIN

The present corrensite consists of chlorite and vermiculite ("swelling chlorite") unit layers, which are regularly instratified according to the scheme . . . ABABAB . . . The chlorite layers are quite uniform among themselves at least in so far as they do not expand with glycol and since on heating at 500°, if they are affected at all, they are all affected in the same way and in a different manner than the vermiculite layers. The latter may be derived from the fact that the alternating sequence of different layers is still present in a considerable proportion after heating at 500° as it is revealed by the glycol treatment of the heated material.

The vermiculite layers must be somewhat different among themselves. They become more uniform by saturation with calcium ions and, to a lesser degree, with magnesium ions. They are rendered more different among themselves by all the other cations used. By glycol treatment they almost become identical. In the majority of cases the vermiculite layers contain more magnesium on the average than regular vermiculite and than the vermiculite layers in the corrensite of Bradley and Weaver. This is shown by the tendency of the second order to stay at a higher spacing than 12 Å after heating for about an hour. Some of the vermiculite layers may contain less magnesium than ordinary vermiculite, especially on saturation with alkalis. The variations among the vermiculite layers are obvious by the lack of higher orders after heating.

Clay minerals may form essentially three different ways: (1) by crystallization from very dilute solutions of their components, (2) by degradation of preexistant well organized layer silicates, and (3) by aggradation of preexistant incompletely organized clay minerals. By crystallization from ultimate components either well-crystallized minerals or all intermediates down to very poorly

developed clay minerals are known to form, but one should not expect both extremes to be represented in one mineral phase. Aggradation at the temperatures of sedimentary environment generally results in rather irregularly organized crystallizations both within each layer unit and with respect to the stacking of the latter because the new components have to be accommodated side by side with the remaining original ones, both of which may be quite different. The apparently well-organized chlorite layers within the corrensite structure strongly hint at a rather perfect preexisting chlorite structure, from which the corrensite has been derived by degradation. The same opinion has also been uttered by Bradley and Weaver. In our case this concept is emphasized by the presence of a small amount of rather well-preserved chlorite.

If one accepts the idea of the origin of corrensite by depletion of chlorite the latter has to be derived from extensive outcrops of chloritic metamorphic rocks. The leaching of the chlorite could have taken place in the soils, during transport, or by diagenesis after deposition. The selective attack on every second layer could be due to a pre-designed difference between alternating brucite sheets. From what is known about macroscopic chlorite, these differences cannot be too great. They should, therefore, become differentiated only on a very mild, balanced and probably long-lasting attack by leaching. This is most likely to occur during diagenesis.

The conclusion that the starting material for the corrensite has been derived from a defined source area has an interesting implication to the geology of the German Triassic. From instances of clay mineral analyses of the Middle Buntsandstein (Huffmann, 1954; Koritnig 1954) underlying the Röt, and of Muschelkalk (Füchtbauer, 1950; Huffmann 1954), overlying the Röt, it seems that the predominant clay mineral in these formations is illite, chlorite either being present only in traces or being entirely absent. Corrensite becomes abundant again in the Middle Keuper (Jasmund, 1954; Lippmann, 1954). There is no reason to believe that a possible corrensite content in the shales within the Middle Buntsandstein and/or the Muschelkalk has been obliterated by diagenesis. The stability of corrensite in marine limestone seems to be certain, especially from the occurrence of Bradley and Weaver's samples. Therefore, the Middle Buntsandstein and Muschelkalk must have had either source areas quite different from the Röt and the Keuper or the chloritic minerals must have become utterly diluted in the Middle Buntsandstein and Muschelkalk by supply of abundant illitic material from farther away. Probably both are true since the basin of sedimentation was certainly more restricted during the Röt and Keuper time so that the influence of more local source areas, as they have to be presumed for the starting material of the corrensite, was much more important for the composition of the sediments of these two formations. Regarding the ubiquity of illite, the dilution of other clay minerals should be quite understandable for a marine environment as that of the Muschelkalk. For the Middle Buntsandstein the facts speak for themselves.

It was first thought by the author that corrensite might be an indicator of saline environment. But the occurrence of Bradley and Weaver's samples refutes this idea. Moreover, corrensite was apparently not observed by Füchtbauer in the Middle Muschelkalk which is at least as saline as the Röt and the Keuper. This agrees with the conclusion that the clay mineral composition of the Röt and the Keuper is mainly caused by provenance, which possibly is the same for both formations.

It is also important to note that red color in a sediment is no indicator of intense weathering but may accompany a rather "unweathered" clay mineral

such as corrensite with its presumably easily alterable chlorite unit layers in the structure.

SIGNIFICANCE OF THE FINDINGS TO SOIL MECHANICS

Shales of the Röt and of the Middle Keuper generally have the common feature that they are very tough and have great strength as long as they are deep enough in the soil and have their natural moisture. On drying and especially on repeated wetting and drying they show very fine erratic fracturing and finally disintegrate to angular fragments which may go down to sand size. This is probably connected with the swelling of the corrensite with water. As soon as there is no more excess of water present the corrensite shrinks to its 29 Å spacing, whereas with the natural moisture it was probably expanded above 29 Å. This shrinkage of the corrensite is accompanied by a shrinkage of the whole shale. Since the water loss proceeds in an irregular manner through a volume of the shale, tensions are built up which finally break up the texture. Shales of the Röt and the Keuper have been known as unreliable construction ground, and under natural conditions, the Lower Muschelkalk, which immediately overlies the Röt, is very susceptible to landslides and related phenomena. They occur where the lower Muschelkalk forms steep escarpments, which include the upper part of the Röt, especially after considerable rainfall. They have been recently described in detail by Ackermann (1953). It is probable that the special character of the Röt shale is at least in part responsible for the landslides. The shale may act both by its great variability of volume with moisture in loosening large size slabs of limestone from their horizontal continuation and as a lubricant when entirely soaked.

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FIGS. 1–8, JUNE, 1956

ESTIMATION OF RECENT SEDIMENT SIZE PARAMETERS FROM A TRIANGULAR DIAGRAM

WILLIAM J. PLUMLEY AND DONALD H. DAVIS
California Research Corporation, La Habra, California

ABSTRACT

Data from 191 size analyses of Recent sediments from several depositional environments were studied to obtain relationships among sediment size measures and sand-silt-clay composition. A simple analytical procedure exists whereby sediment size parameters of median, mean, deviation measure, and skewness of Recent sediments may be estimated from a three-component plot of sand, silt, and clay percentages. The three-component analysis is made easily by abbreviated size analysis methods, and the size parameters are obtained graphically from the three-component plot. Conversely, if the median and deviation measure of a sediment sample are known, the composition of the sediment may be obtained in terms of percent sand, silt, and clay. Thus, a one to one correspondence exists between points on the triangular diagram and pairs of median and deviation measure values (excluding the periphery of triangle). The estimation method for obtaining sediment size parameters will facilitate size analysis of large numbers of Recent sediment samples were semiquantitative data are desired.

INTRODUCTION

The size-frequency distribution is a fundamental physical property of a clastic sediment or sedimenatry rock. It may be considered as a direct expression of the physical conditions or the kinetic energy conditions within the environment of deposition and as an indirect expression of the kinetic energy of the transportational environment and the material available for transport.

Modern statistical approaches to analysis of the size-frequency distribution have furnished methods for representing the physical environment in terms of size parameters, such as the mean and median, which are measures of the central tendency; the quartile deviation and standard deviation, which are measures of the sorting or spread of the distribution about the mean size; and the skewness, which is a measure of the asymmetry of the distribution. These parameters are usually derived graphically from cumulative curves drawn from data obtained by sieve, pipette, hydrometer, or similar standard size-analysis methods (Krumbein and Pettijohn, 1938).

In addition to standard size-analysis methods, a few shortcuts have been devised for obtaining these data. Emery and Gould (1948) used a comparison method by which large numbers of Recent sediments were analyzed in a relatively short time. Within each area of study, approximately 10 percent of the samples were analyzed by sieving and pipetting and were then arranged in glass vials in a gradational scale of known size parameters. Unknown samples were compared to the "knowns" by eye and with a microscope. Dapples, Krumbein, and Sloss (1953, pp. 306–307) suggested a method for obtaining a Sorting Index based on rapid measurement and estimation, and adaptable to small samples.

$$\text{Sorting Index} = \frac{\text{Number of } \phi \text{ classes in modal two-thirds}}{(\text{Number of } \phi \text{ classes in entire size range})^2}$$

In addition to the cumulative curve and size parameters derived therefrom, many other methods have been used to portray the physical nature of sediments. The three-component or triangular diagram, for example, has been particularly effective. On such a diagram a sediment sample is represented as a point, the location of which is determined by the percent sand (2–1/16 mm), silt (1/16−1/256 mm), and clay (<1

/256 mm) in the sample. The most recent publications referring to such a diagram are those of Shepard (1954), and Wimberley (1955).

The usefulness of a triangular diagram may be considerably enhanced if a plot of sand-silt-clay percentages can be translated easily into parameters of the size frequency distribution. Furthermore, a sand-silt-clay diagram may be prepared from size data obtained from only one sieve fraction and one pipette fraction. Estimation of size parameters from such easily obtained data is an attractive prospect as compared with the laborious and time-consuming methods required for complete size analysis.

The purpose of this paper is to show the correspondence between size[1] parameters obtained from a triangular diagram and those obtained by the method of Inman (1952) which requires analysis of a large part of the distribution function. The specific sample parameters used in this comparison are those defined by Inman as:

$$M_\phi = \text{Phi Mean} = \frac{Q_{16}+Q_{84}}{2}$$

Where

Q_{16} = the value of phi at the 16 percentile

Q_{84} = the value of phi at the 84 percentile

Md_ϕ = Phi Median = 50 percentile

$$\sigma_\phi = \text{Phi Deviation Measure} = \frac{Q_{84}-Q_{16}}{2}$$

$$\alpha_\phi = \text{Phi Skewness} = \frac{M_\phi - Md_\phi}{\sigma_\phi}$$

With the exception of the phi median, which is exact, all of Inman's parameters are approximations and do not necessarily closely approximate the theoretical mean, standard deviation, and skewness of a size-frequency distribution (Cadigan, 1954). For example, the phi mean is

[1] In the remainder of this discussion "size" is implied to mean "log of diameter." The phi scale is related to the ordinary size scale by the expression: $\phi = -\log_2 d$, where d is diameter in mm (Krumbein, 1934).

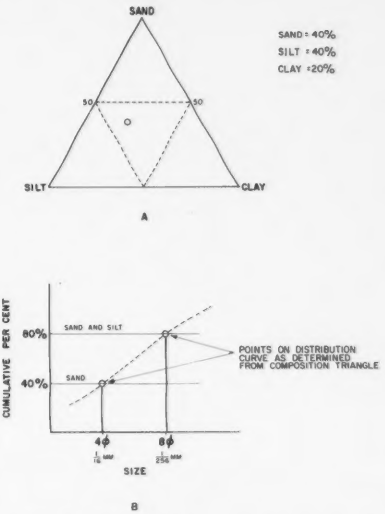

FIG. 1.—Relation between sediment composition and distribution curve.

defined as the average of the 16 and 84 percentile. In many fine-grained sediments which contain a large percent of clay-size particles, the cumulative curve approaches an asymptotic value in the region of the 84 percentile. The value of the phi mean calculated from the 16 and 84 percentiles in such a case may be considerably different than the actual value of the phi mean. In this example, the phi standard deviation may be even more in error. Inman (1952, p. 143) states that "the approximation of the graphic measures to the corresponding theoretical moment measures decreases as the skewness of the distribution increases."

Another factor, however, enters into the error problem of Inman's size parameters that perhaps compensates for the error in approximating the mean, standard deviation, and skewness in the fine-grained sediments. The size frequency distribution representative of depositional conditions of fine-grained marine

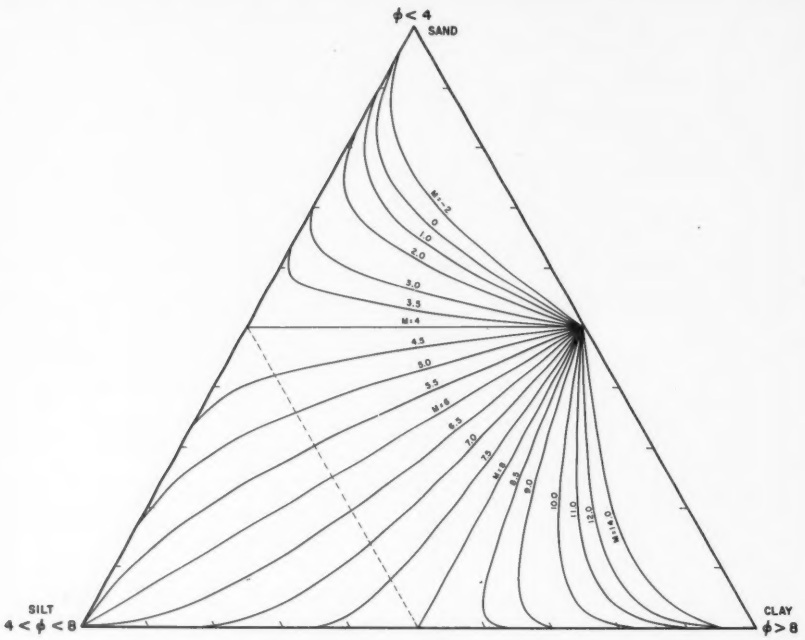

FIG. 2.—Relation between phi mean (Mϕ) and composition triangle (normal distribution function). Phi mean = phi median (Mdϕ).

sediments probably is not duplicated when a sediment is dispersed in a peptizing solution and analyzed by pipette or hydrometer methods. Within a marine environment, under conditions other than density flow, clay-size particles usually flocculate and settle as aggregates. These aggregates are dispersed during analysis and the data plot as cumulative curves that have long "tails" in the fine sizes. Frequently the sediment never completely settles during the time of the analysis and the calculated frequency distribution is "open ended." Thus, by ignoring the part of the frequency distribution greater than 84 per cent, Inman utilizes a portion of the size-frequency distribution that probably is most representative (as far as can be determined with present-day analysis methods) of sedimentary conditions within a depositional environment.

Whereas Inman's size parameters were utilized in the three-component analysis that follows, no implication other than convenience is necessarily implied. Other parameters of the size distribution, exact or approximate, may be substituted according to the reader's inclination, but similar relationships will exist among such parameters and a three-component plot. It is understood, however, that such parameters will not be equivalent.

SIZE DISTRIBUTION FUNCTIONS OF SEDIMENTS

A triangular diagram that gives the percent sand, silt, and clay of a sediment sample is sufficient (except on the periphery) to determine two points on the

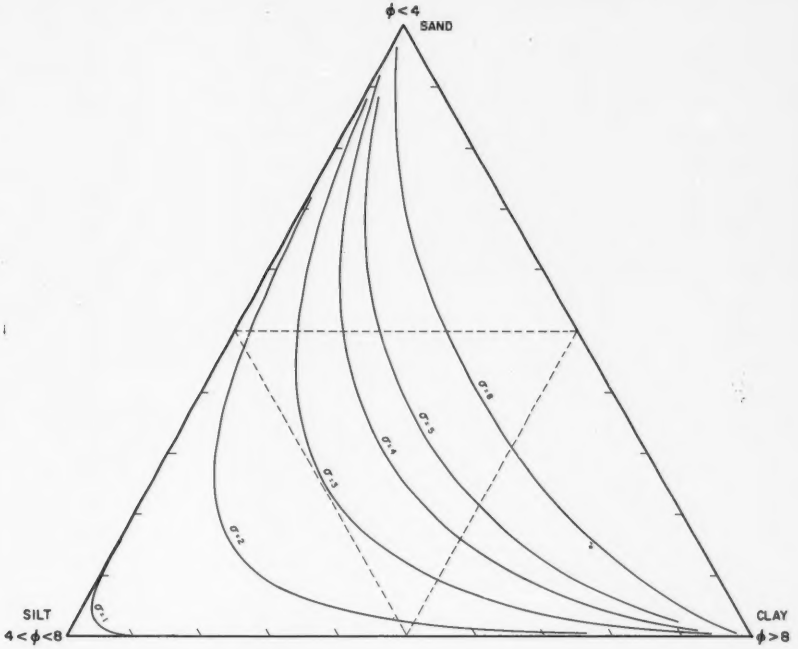

FIG. 3.—Relation between phi standard deviation (σ_ϕ) and composition triangle (normal distribution function).

grain-size distribution curve for the sample (fig. 1). If the size distribution functions for all sedimentary samples belong to a class of distribution functions which depend on only two parameters, then the two points (fig. 1B) may be sufficient to determine the two parameters and thus the distribution function. In other words, the distribution curve through the two points will be determined.

If it is assumed that the variable ϕ for sediments has a normal distribution function, which is a function completely defined by two parameters—the mean (M_ϕ) and standard deviation ($\sigma\phi$), then values of the mean and standard deviation in relation to sand-silt-clay composition may be calculated. Figure 2 shows the relation between M_ϕ (or a normal distribution function) and a composition triangle; figure 3 shows the relation between σ_ϕ (of the same function) and the composition triangle.

The diagrams of mean size and sorting shown in figures 2 and 3 are based on the assumption that all sediment size distributions can be described by a normal distribution function. The fact that many sediments are highly skewed or asymmetrical demonstrates, however, that some class of functions other than normal functions is operative.

Basic sediment size data were studied in order to test the degree of application of a normal function to sediment size-frequency distributions, and more important as far as this paper is concerned, to establish general relationships between sand-silt-clay composition and statistical

TABLE 1.—*Sediment size data (after Hough, 1935)*
All size data are in phi units

Sample No.	Percentile Q_{16}	Q_{25}	Q_{50} (Median)	Q_{75}	Q_{84}	Phi Mean (M_ϕ)	Phi Deviation Measure (σ_ϕ)	Phi Skewness (α_ϕ)	Sand %	Silt %	Clay %
BL1	3.3	3.4	4.0	4.7	5.1	4.2	0.9	0.22	51	46	3
BL2	5.0	5.8	6.8	8.8	9.1	7.0	2.1	0.12	12	58	30
M15	1.9	2.8	3.1	3.9	4.4	3.1	1.2	0	78	20	2
Sa1	4.1	4.5	5.2	6.7	7.5	5.8	1.7	0.35	14	75	11
Sa2	3.6	3.9	4.5	5.0	5.7	4.6	1.1	0.16	29	68	3
Sa3	3.2	3.4	3.9	5.0	7.5	5.3	2.2	0.65	54	29	17
Sa15	4.6	5.5	6.9	8.5	9.2	6.9	2.3	0	5	62	33
Sa16	6.0	7.5	9.1	10.4	10.8	8.4	2.4	−0.29	0	30	70
SH1	3.5	4.8	6.0	7.8	9.0	6.2	2.8	0.08	18	59	23
SH2	4.1	4.5	5.1	6.2	7.0	5.5	1.5	0.31	15	76	9
SH3	4.0	4.3	4.7	5.7	6.5	5.2	1.3	0.44	15	78	7
SH4	3.5	3.8	4.3	4.7	5.1	4.3	0.80	0.06	37	62	1
SJ2	4.0	4.2	4.5	4.9	5.5	4.7	0.75	0.26	17	78	5
SJ3	3.5	3.7	4.0	4.7	5.1	4.3	0.80	0.31	46	49	5

size parameters of Inman. The data were obtained from the literature, from size studies of California Research Corporation, and from unpublished work of other laboratories.

A total of 191 Recent sediment size analyses were obtained from the following sources: Hough (1935), 14 Lake Michigan bottom sediments; Krumbein and Aberdeen (1937), 61 Barataria Bay bottom sediments; K. O. Emery (unpublished data), 55 West Coast bay, shelf and shelf-basin sediments; Scripps Institution of Oceanography (unpublished data), 51 Gulf Coast bay, delta, and shelf bottom sediments; and California Research Corporation (unpublished data), 10 Gulf of Mexico bottom sediments. These data comprise a wide range of sedimentary (geomorphic) environments; open continental shelf, lake, bay, shelf-basin, and bay near delta (tidal lagoon).

With the exception of the Scripps samples, all size data were obtained by the same method of size analysis. The Scripps analyses were made with a sedimentation tube for the sand-size fractions and a hydrometer for the less-than-sand-size fractions. All other analyses were made by standard sieve and pipette methods. The results obtained by these different methods of analysis appear to be comparable in terms of size parameters.

The relative contributions of clastic materials (terrigenous clastics and transported shells) and accretionary materials (accumulation of shells *in situ*) to the size distributions of the samples are unknown. Nonclastic materials are negligible in the samples analyzed by California Research Corporation, Krumbein and Aberdeen (1937), and Hough (1935). The contribution of shell material in the Scripps samples and those of Emery may be appreciable in some cases. Because of insufficient data on the shell contributions and the inherent difficulty of distinguishing between accretionary and transported shell material, this factor has been neglected in the analysis of the data. It is not unreasonable to attribute some of the scattering of data in following figures to the mixing of sedimentary particles from two entirely different sources and by different processes (transported clastic materials and accretionary shell materials *in situ*).

The size data of each sample were plotted as a cumulative curve, and graph-

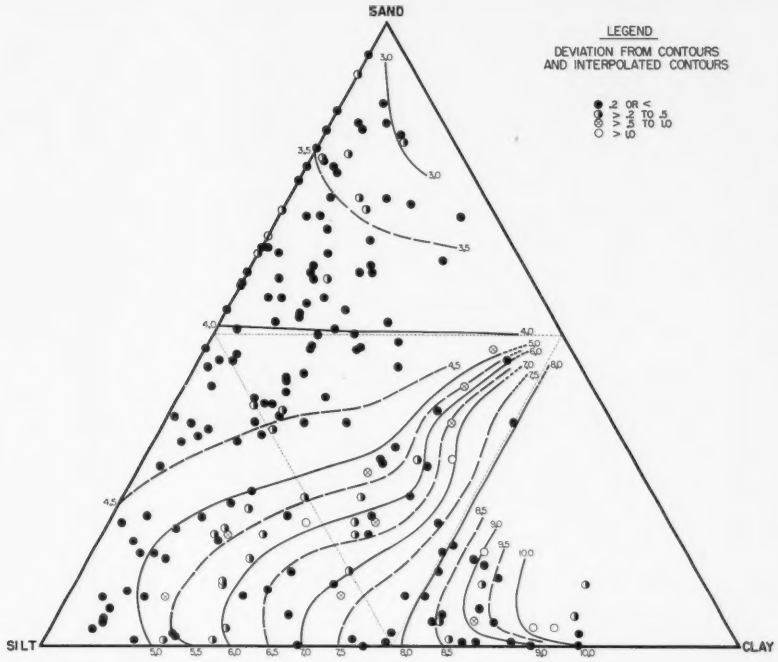

FIG. 4.—Relation between phi median (Mdϕ) and composition triangle (Recent sediments).

ical computations of size parameters were made after the method of Inman (1952). In addition, the percentages of sand, silt, and clay were obtained from the cumulative curves. The data for all samples are listed in tables 1 through 5.

Phi Median (Md$_\phi$)

In figure 4 each sample is plotted as a circle in a position determined by its relative percentages of sand, silt, and clay. On the working graph from which this figure was derived, the values of Md$_\phi$ as listed in tables 1–5 were plotted beside each sample point and the graph was then contoured. As noted in the legend for figure 4, each sample point is designated in relation to its deviation from a contour line or interpolated contour line. Thus, 75 percent of the samples have medians (as determined from cumulative curves) that are within ± 0.2 phi units of the indicated contour line; less than 10 percent of the samples have medians that deviate more than ± 0.5 phi units from the indicated contour line. The areas of the triangle comprising mixtures of sand and clay with little silt unfortunately are sparsely represented in the sample coverage. Such sediment compositons, however, are believed to be relatively rare in comparison to compositions containing greater proportions of silt.

An interesting comparison may be made between this diagram and the one derived mathematically from a normal distribution function (fig. 2). The configuration of the median contours in figure 4

TABLE 2.—*Sediment size data (after Krumbein and Aberdeen, 1937) Barataria Bay, Louisiana*

All size data are in phi units

Sample No.	Percentile					Phi Mean (M_ϕ)	Phi Deviation Measure (σ_ϕ)	Phi Skewness (α_ϕ)	Sand %	Silt %	Clay %
	Q_{16}	Q_{25}	Q_{50} (Median)	Q_{75}	Q_{84}						
7	3.4	3.7	4.4	6.2	7.4	5.4	2.0	0.50	39	48	13
8	4.4	4.9	7.0	9.1	10.4	7.4	3.0	0.13	10	53	37
9	3.9	4.2	4.8	6.5	7.9	5.9	2.0	0.55	18	66	16
10	2.6	3.0	3.4	3.8	4.0	3.3	0.70	−0.14	84	12	4
11	3.5	3.7	4.0	5.1	6.7	5.1	1.6	0.68	39	50	11
14	3.0	3.1	3.5	4.0	4.5	3.7	0.75	0.26	76	19	5
15	3.1	3.3	3.9	5.7	7.3	5.2	2.1	0.61	53	36	11
16	3.3	3.6	4.6	6.8	7.9	5.6	2.3	0.43	34	51	15
17	3.3	3.6	4.3	6.0	7.2	5.2	1.9	0.47	40	49	11
19	3.9	4.2	5.0	7.0	8.2	6.0	2.1	0.45	19	64	17
20	3.9	4.4	5.5	7.3	8.1	6.0	2.1	0.23	17	66	17
22	2.5	2.7	3.1	3.6	4.1	3.3	0.8	0.25	83	12	5
23	3.1	3.4	4.5	7.0	8.6	5.6	2.7	0.40	40	39	21
24	3.2	3.4	3.8	4.8	6.4	4.8	1.6	0.62	59	31	10
25	3.3	3.5	4.0	6.0	7.7	5.5	2.2	0.68	48	37	15
26	3.3	3.5	4.0	6.5	7.9	5.6	2.3	0.69	50	35	15
27	3.2	3.4	3.9	4.7	6.9	5.0	.8	0.61	59	29	12
28	2.7	2.9	3.3	3.9	4.6	3.6	0.9	0.33	77	19	4
29	2.7	3.0	3.8	5.3	7.0	4.8	2.6	0.38	55	34	11
30	3.1	3.3	3.9	4.8	6.0	4.5	1.5	0.40	56	37	7
31	2.8	2.9	3.2	4.5	6.5	4.6	1.8	0.78	72	18	10
32	3.4	3.7	4.4	6.5	7.7	5.5	2.1	0.52	39	47	14
33	3.3	3.6	4.3	6.3	7.8	5.5	2.2	0.54	41	44	15
38	3.7	4.1	5.1	7.0	8.0	5.8	1.4	0.50	23	61	16
40	3.5	3.7	4.2	5.4	7.5	5.5	2.0	0.65	43	43	14
42	2.7	2.9	3.3	4.2	5.4	4.1	1.6	0.25	70	30	—
42	3.4	4.3	5.6	8.0	9.1	6.2	2.8	0.21	21	54	25
44	4.3	4.5	5.5	7.5	8.6	6.4	2.1	0.42	10	69	21
45	4.0	4.2	4.7	7.0	8.3	6.1	2.1	0.66	18	64	18
47	3.4	3.7	4.4	5.8	7.4	5.4	2.0	0.50	36	51	13
48	3.8	4.1	4.9	7.2	8.4	6.1	2.3	0.52	22	59	19
50	2.9	3.0	3.4	3.	4.1	3.5	0.6	0.16	80	20	—
52	3.1	3.2	3.6	4.0	4.4	3.7	0.65	0.15	77	23	—
53	2.8	2.9	3.3	3.8	4.1	3.4	0.65	0.15	83	17	—
54	2.9	3.0	3.5	4.2	4.8	3.8	0.95	0.31	69	27	4
55	3.0	3.2	3.6	4.4	6.1	4.5	1.5	0.60	67	25	8
56	4.0	4.5	5.5	7.7	8.9	6.4	2.4	0.37	14	63	23
57	2.6	2.8	3.2	3.6	3.9	3.2	0.65	0	86	14	—
60	2.6	2.8	3.3	3.9	4.4	3.5	0.9	0.22	78	20	2
61	3.1	3.3	3.7	4.4	4.9	4.0	0.85	0.35	63	34	3
62	3.1	3.3	4.1	6.5	7.9	5.5	2.4	0.58	48	37	15
64	3.5	3.7	4.3	6.4	8.0	5.7	2.3	0.63	37	47	16
65	2.9	3.1	3.6	4.1	4.5	3.7	0.8	0.12	72	28	0
66	3.5	3.7	4.2	5.5	7.9	5.7	2.2	0.67	38	46	16
67	3.3	3.6	4.1	5.6	7.4	5.3	2.1	0.50	43	43	14
70	4.6	4.7	6.0	8.0	8.9	6.7	2.1	0.33	8	67	25
74	4.5	4.9	6.5	8.2	8.9	6.7	2.2	0.09	9	63	28
75	2.9	3.3	3.9	5.4	7.0	4.9	2.1	0.50	53	36	11
79	3.1	3.3	3.9	4.7	5.7	4.4	1.3	0.38	58	42	—
82	2.8	3.2	3.8	4.5	4.9	3.8	1.1	0	56	39	5
82	3.1	3.4	4.0	4.7	6.3	4.7	1.6	0.43	52	40	8
87	3.1	3.3	3.8	5.0	7.3	5.2	2.1	0.66	56	31	13
88	3.2	3.4	3.8	4.8	6.8	5.0	1.8	0.66	60	31	9

TABLE 2—*continued*

Sample No.	Percentile					Phi Mean (M_ϕ)	Phi Deviation Measure σ_ϕ	Phi Skewness (α_ϕ)	Sand %	Silt %	Clay %
	Q_{16}	Q_{25}	Q_{50} (Median)	Q_{75}	Q_{84}						
89	2.9	3.3	3.8	4.6	5.4	4.1	1.3	0.25	60	40	—
91	3.3	3.5	3.9	4.7	5.2	4.2	0.95	0.31	54	46	—
92	3.5	4.0	4.9	7.2	8.4	5.8	2.5	0.36	25	57	18
93	2.3	2.6	3.5	4.4	4.9	3.6	1.3	0.07	63	37	—
94	2.9	3.1	3.7	4.6	5.6	4.2	1.4	0.35	61	30	9
95	3.3	3.4	3.7	4.5	5.5	4.4	1.1	0.63	63	27	10
96	2.7	3.0	3.7	4.4	5.0	3.8	1.2	0.09	66	34	—
97	2.9	3.2	3.8	4.9	5.9	4.4	1.5	0.40	58	42	—

is similar to the configuration of the mean contours in figure 2. Because a normal frequency curve is symmetrical, the mean and median are identical in figure 2. Other similarities between the two diagrams are in the position of the 4 and 8 phi contours, which in both diagrams follow the 50 percent sand and 50 percent clay composition lines respectively (exactly in figure 2; approximately in figure 4). It is interesting to note that the $Md_\phi = 4$ line must be identical to the 50 percent sand line by definition. A median of phi = 4 defines a sediment composed 50 percent of particles of sand size or greater and 50 percent of particles of less than sand size. A similar relationship exists for the $Md_\phi = 8$ line and the 50 percent clay line.

The major difference in the two diagrams lies in the area of greater than 50 percent sand. Whereas the "normal" diagram contains mean contours in this area from 4 to −2 phi, the median contours of figure 4 do not drop below 3 phi. The error in this estimation of the median from a triangular diagram may be large in the immediate area of the sand apex of the triangle. A pure sand sample, for example, which could range from 4 to −1 phi units in median size would not be plotted on this diagram.

This difficulty may be circumvented for coarse-grained sediments by constructing triangular diagrams having as apexes very fine sand and finer (>3 phi), fine sand (2 to 3 phi), and medium sand and coarser (<2 phi). From such a plot the medians of the sand sizes would be of comparable accuracy to those of the silts in the sand-silt-clay diagram.

For practical purposes samples composed of greater than 90 percent sand are not plotted. Differences between these two diagrams (figs. 2 and 4) are due to the fact that not all sediments have normal size-frequency distributions. This fact is illustrated more completely in following diagrams.

Phi Mean (M_ϕ)

Figure 5 is a plot similar to that of figure 4, but values of M_ϕ have been contoured. If sediments had normal frequency distributions, this chart would be identical to that of the phi median (fig. 4). The greatest difference in the two charts is in the upper half where the contours cross at a large angle. The greatest divergence in the median and mean contours occurs in general where the sediments are most highly skewed, thus indicating a departure from a normal distribution function. The number of samples plotted on the phi mean chart is less than the number on the phi median chart because the phi mean could not be computed for all samples. Computation of the phi mean by the method used requires a value for the 84 percentile, and this value was not always available for highly skewed fine-grained sediments. The deviation of sample mean values from ex-

TABLE 3.—*Sediment size data (after Emery, University of Southern California) coastal waters of West Coast North America*
All size data are in phi units

Sample No.	Percentile					Phi Mean (M_ϕ)	Phi Deviation Measure (σ_ϕ)	Phi Skewness (α_ϕ)	Sand %	Silt %	Clay %
	Q_{16}	Q_{25}	Q_{50} (Median)	Q_{75}	Q_{84}						
Southern California											
Core 1634											
6.5–11 feet	5.3	5.8	7.0	9.1	10.1	7.7	2.3	0.30	0.1	63	37
16–20 feet	4.4	4.6	5.6	7.9	9.0	6.7	2.3	0.47	1	75	24
40–46 feet	4.1	4.4	5.3	7.6	9.0	6.5	2.4	0.50	10	69	21
Core 1635											
0–5 feet	5.3	6.1	7.7	9.3	9.8	7.5	2.2	−0.09	1	55	44
8–14.5 feet	4.6	5.0	6.3	7.8	9.4	7.0	2.4	0.29	3	72	25
Core 1981											
3–8 feet	6.5	7.0	8.7	10.7	11.7	9.1	2.6	0.15	0.5	39.5	60
32–38 feet	6.1	6.7	8.3	9.6	10.5	8.3	2.2	0	4	42	54
50–56 feet	6.1	6.6	7.9	9.8	10.5	8.3	2.2	0.18	0.5	50.5	49
Core 1982											
15–17 feet	3.7	4.2	5.7	9.2	10.8	7.2	3.5	0.42	20	45	35
17–19 feet	3.4	3.7	4.1	5.7	7.8	5.6	2.2	0.68	44	40	16
55–59 feet	1.8	2.1	2.9	3.6	4.0	2.9	1.1	0	84	8	8
Core 1983											
0–6 feet	6.5	7.3	8.8	10.4	11.3	8.9	2.4	0.04	0.5	37.5	62
30–36 feet	5.7	6.7	8.3	10.0	10.8	8.2	2.5	−0.04	4	41	55
60–66 feet	4.9	5.9	7.9	9.6	9.9	7.4	2.5	−0.20	2	49	49
Core 1984											
33.7–34 feet	4.4	5.2	8.0	10.3	11.3	7.8	3.4	−0.05	12	37	51
34–39 feet	6.4	7.2	8.9	10.6	11.5	8.9	2.5	0	0.5	32.5	67
92.5–98 feet	5.4	6.0	7.8	10.0	10.9	8.1	2.7	0.11	—	54	46
Core 1986											
17–22 feet	4.6	5.3	7.9	9.7	10.3	7.4	2.8	−0.18	8	44	48
28–34 feet	5.1	6.1	8.4	10.1	10.8	7.9	2.8	−0.18	5	40	55
Core 1998											
6–11 feet	4.5	5.0	6.7	9.2	9.9	7.2	2.7	0.18	12	50	38
72–76 feet	3.9	4.5	6.2	9.8	10.7	7.3	3.4	0.32	18	46	36
Cedros Island Area											
Mexico											
1894	3.5	3.7	4.1	4.8	6.2	4.9	1.4	0.57	45	53	2
1935	3.2	3.4	3.6	3.8	3.9	3.6	0.35	0	92	8	—
1943	3.4	3.5	3.7	4.1	4.3	3.9	0.45	0.44	69	25	6
1982	3.2	3.3	3.7	4.0	4.1	3.7	0.45	0	75	25	—
2016	3.1	3.3	3.7	4.3	4.6	3.9	0.85	0.24	63	37	—
2018	3.4	3.7	4.2	4.6	4.8	4.1	0.70	−0.14	42	54	4
3073	3.1	3.3	4.1	4.9	5.5	4.2	1.2	0.08	46	51	3
Todos Santos Bay											
Mexico											
2317	3.5	3.8	4.3	5.0	5.5	4.5	1.0	0.10	36	60	4
2391	3.0	3.5	4.3	4.7	5.0	4.0	1.0	−0.15	34	61	5
2398	4.2	4.3	4.6	5.0	5.6	4.9	0.70	0.43	6	87	7
2399	4.3	4.5	4.8	5.2	5.7	5.0	0.70	0.29	3	91	6
2407	4.2	4.3	4.7	5.0	5.4	4.8	0.60	0.17	8	87	5
2411	2.5	3.5	4.3	4.7	5.1	3.8	1.3	0.38	33	63	4
2415	2.7	2.8	3.7	4.4	4.8	3.8	1.1	0.09	59	36	5
2418	3.8	4.1	4.5	4.8	5.1	4.6	0.65	0.15	20	78	2
2545	3.3	3.6	4.1	4.5	4.7	4.0	0.70	−0.14	48	52	—
2599	4.6	4.7	5.3	7.5	8.3	6.5	1.9	0.68	2	80	18
2601	3.8	4.3	5.2	6.0	6.7	5.3	1.5	0.07	19	71	10
2645	4.1	4.3	4.7	5.2	6.0	5.1	0.95	0.42	9	83	8
2691	3.1	3.4	3.8	4.3	4.5	3.8	0.70	0	64	35	1
2702	4.8	5.0	5.7	7.8	10.5	7.7	2.9	0.69	2	80	18
3727	4.7	4.9	5.8	7.1	8.3	6.5	1.8	0.38	1	82	17
3765	4.5	4.6	4.9	6.7	7.7	6.1	1.6	0.74	1	86	13
3776	4.3	4.4	4.6	4.8	5.0	4.6	0.35	0	4	89	7
San Francisco Area											
2735	3.6	3.8	4.6	5.8	7.3	5.5	1.9	0.47	33	55	12
2749	4.3	4.5	5.0	6.8	8.0	6.2	1.9	0.63	8	81	11
2838	3.8	4.1	5.0	6.7	8.0	5.9	2.1	0.42	21	66	13
2845	4.2	4.4	4.8	6.6	8.4	6.3	2.1	0.71	8	78	14
2852	3.5	3.7	4.3	4.9	5.8	4.6	1.1	0.27	35	59	7
2855	4.4	4.5	4.8	5.6	6.5	5.4	1.0	0.60	4	89	7
Santa Rosa-Cortes Ridge											
3415	3.0	3.2	3.6	3.9	4.5	3.7	0.75	0.13	79	16	5
3609	1.8	2.7	4.3	5.7	6.5	4.1	2.3	−0.08	35	49	16
San Diego Area											
3005	3.8	4.1	4.5	4.9	5.3	4.5	0.75	0	21	74	5
3014	3.5	3.7	4.1	4.8	5.5	4.5	1.0	0.40	47	48	5

TABLE 4.—*Sediment size data (Scripps Institution of Oceanography) Gulf of Mexico*

All size data are in phi units

Sample No.	Percentile					Phi Mean (M_ϕ)	Phi Deviation Measure (σ_ϕ)	Phi Skewness (α_ϕ)	Sand %	Silt %	Clay %
	Q_{16}	Q_{25}	Q_{50} (Median)	Q_{75}	Q_{84}						
San Antonio Bay											
S35A	3.0	3.2	3.7	4.7	9.0	6.0	3.0	0.76	61	22	17
S37A	3.0	3.2	3.5	4.1	4.6	3.8	0.8	0.37	72	14	14
S39A	3.2	3.4	4.0	5.8					48	30	22
S40A	2.7	3.0	3.6	9.0					62	11	27
S43A	3.0	3.2	6.0						46	10	44
S45A	3.3	3.8	5.4						30	31	39
S46A	3.0	3.3	4.1	5.8	10.1	6.5	3.5	0.68	48	30	22
S47A	3.6	4.0	4.9	8.7					24	50	26
S51A	3.1	3.2	3.9	7.9					52	24	24
S57A	4.0	4.2	8.0						16	33	51
S58A	4.7	6.8	9.5						4	33	63
S60A	7.1	7.9	10.1						5	21	74
S62A	2.5	2.7	3.1	4.4	6.3	4.4	1.9	0.68	70	18	12
S64A	3.9	4.1	4.4	9.6					20	52	28
S66A	3.3	3.9	4.6	10.4					28	39	33
S67A	2.9	3.1	3.6	4.3	8.2	5.5	2.6	0.73	60	24	16
Rockport Area											
J10A	3.2	3.3	3.7	4.5	7.3	5.2	2.0	0.75	65	20	15
J11B	3.2	3.4	4.0	8.6	12.0	7.6	4.4	0.81	49	24	27
J12A	3.2	3.5	7.5						36	23	41
J13A	3.2	3.5	6.2						38	24	38
J14A	3.1	3.3	4.3	9.0	10.3	6.7	3.6	0.66	45	26	29
J15A	3.3	3.8	6.1	10.6					29	30	41
J51B	3.1	3.2	3.5	4.3	9.2	6.1	3.0	0.86	71	11	18
J52BA	3.8	4.0	6.0	11.0	12.0	7.9	3.1	0.61	24	35	41
J52BB	3.5	3.7	4.8	9.9	11.0	7.2	3.7	0.64	30	36	34
J53B	3.0	3.2	4.0	4.7	10.2	6.6	3.6	0.72	50	30	20
J54B	3.1	3.3	3.8	4.6	9.2	6.1	3.0	0.76	60	22	18
J55B	3.6	3.9	4.4	8.4	11.4	7.5	3.9	0.79	30	44	26
J91DB	4.0	4.3	8.8						14	31	55
J92DC	3.8	4.3	7.5						20	33	47
J93DB	4.3	6.1	9.4						11	29	60
J92DA1	4.2	4.7	8.2						8	41	51
J92DA2	3.3	3.5	4.1	4.7	5.2	4.2	0.9	0.11	48	41	11
Breton Sound											
BS150	5.0	7.5	9.5						6	34	60
BS151	3.8	4.5	5.5						20	42	38
BS154	3.0	3.1	3.3	3.5	3.8	3.4	0.4	0.25	87	7	6
BS157	4.0	4.2	4.6	9.0	10.6	7.3	3.3	0.81	15	56	29
BS164	6.7	8.6	10.7						10	17	73
Arkansas Bay											
A154C	3.0	3.1	3.4	8.5	10.9	6.9	3.9	0.89	69	5	26
A155C	3.3	3.5	7.9						36	14	50
A156C	3.2	3.4	4.8						42	18	40
A158C	2.8	3.0	3.2	3.4	3.6	3.2	0.4	0	87	2	11
A187C	4.9	7.0	11.1						3	28	69
A188C	4.1	4.5	9.6						10	32	58
A189C	4.5	5.6	10.1						4	36	60
Gulf of Mexico (Mississippi River Area)											
GM311	4.2	5.0	9.1						13	30	57
GM312	3.3	3.7	5.1	10.2	11.5	7.4	4.1	0.56	32	33	35
GM314	5.2	6.1	8.9						1	41	58
GM316	5.4	7.5	10.3						3	25	72
GM317	1.9	2.2	2.6	3.2	5.0	3.4	1.5	0.53	81	7	12
GM318	6.0	8.1	10.4						2	12	76

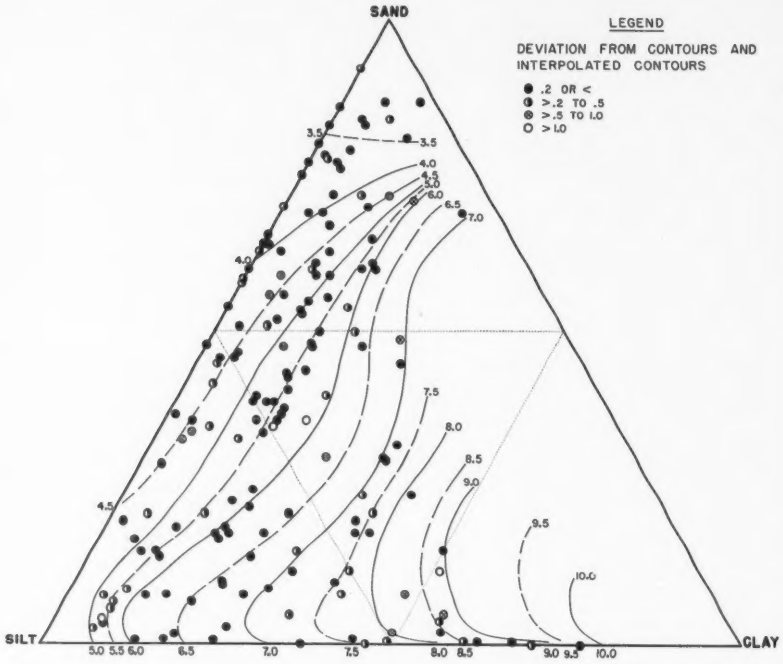

FIG. 5.—Relation between phi mean (Mϕ) and composition triangle (Recent sediments).

TABLE 5.—*Sediment size data (California Research Corporation)*
Gulf of Mexico, Louisiana Coast
All size data are in phi units

Sample No.	Percentile					Phi Mean (M_ϕ)	Phi Deviation Measure (σ_ϕ)	Phi Skewness (α_ϕ)	Sand %	Silt %	Clay %
	Q_{16}	Q_{25}	Q_{50} (Median)	Q_{75}	Q_{84}						
9960-68-1	3.4	3.7	4.4	6.3	10.5	6.9	3.5	0.71	36	44	20
-3	3.7	4.2	6.1	9.6	12.2	8.0	4.2	0.43	21	42	37
-4	3.5	3.5	3.9	5.8	6.8	5.1	1.9	0.75	51	42	7
-5	3.5	3.8	5.1	9.3	10.7	7.1	3.6	0.56	30	36	34
-6	4.1	5.1	8.0	10.4	14.0	9.1	4.9	0.21	15	35	50
-7	3.9	4.2	6.3	10.2	12.0	7.9	4.1	0.32	18	44	38
-8	3.5	3.7	4.4	5.8	8.2	5.9	2.3	0.61	36	48	16
-9	3.7	4.0	5.7	9.0	9.9	6.8	3.1	0.35	24	42	34
9960-47-1	4.4	4.9	6.4	9.5	10.3	7.3	2.9	0.31	8	53	39
-2	7.4	8.2	10.1	11.7	12.5	9.9	2.5	−0.8	—	23	77

trapolated contour lines is slightly larger than the deviation for the median values; 67 percent of the samples have means that are within ± 0.2 phi units of the indicated value of the contour line, and 10 percent have means that deviate more than ± 0.5 phi units.

Phi Deviation Measure (σ_ϕ)

Figure 6 is a plot of phi deviation measure in relation to sand-silt-clay composition. This chart is similar to the chart of standard deviation plotted for a normal size-frequency distribution (fig. 3). The greatest discrepancy between the two deviation charts occurs in the upper one-half to two-thirds of the diagram. In this area the samples are more poorly sorted (higher σ_ϕ values) than samples with normal frequency distributions. Figure 6 contains fewer sample points than the median chart because σ_ϕ is determined from the difference between the 84 and 16 percentiles, and the former often was not determinable. The deviation of the sample sorting values from extrapolated contour lines is comparable to those for the median and mean; 72 percent deviate less than ± 0.2 phi units, and 9 percent deviate more than ± 0.5 phi units.

Phi Skewness (α_ϕ)

Phi skewness values were computed for each sample and plotted on the composition triangle in figure 7. Sample skewness values were somewhat erratic and thus smooth contours could not be drawn that would be of value in estimating the skew-

FIG. 6.—Relation between phi deviation measure (σ_ϕ) and composition triangle (Recent sediments).

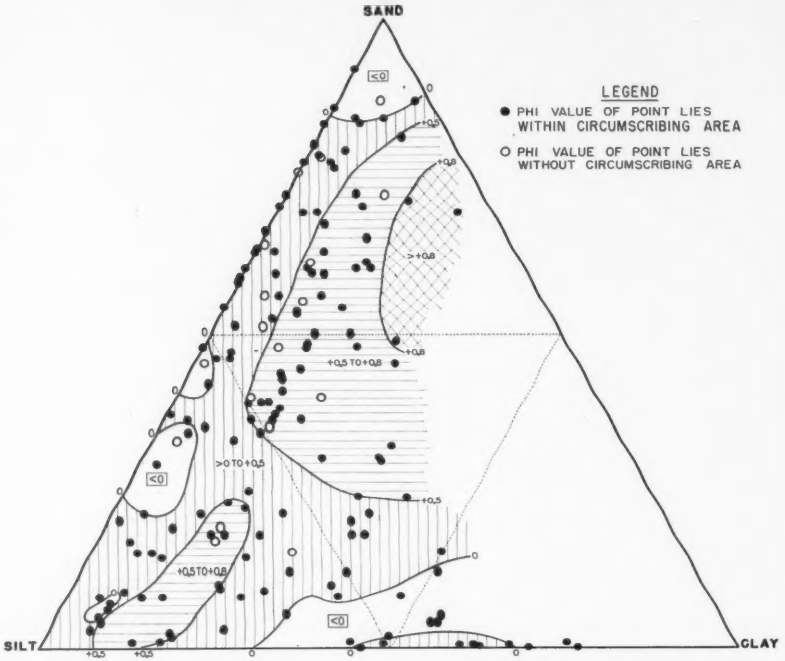

FIG. 7.—Relation between phi skewness (α_ϕ) and composition triangle (Recent sediments).

ness within close limits. However, certain trends in skewness are apparent and may be shown by areas on the diagram that enclose samples within rather wide ranges of skewness. These areas are outlined by the skewness values of 0, +0.5, and +0.8. Mixtures of sand and silt with little clay are characterized by small values of skewness (± 0.5). A similar area occurs with mixtures of silt and clay with little sand. An exception to this occurs in the lower left part of the triangle which contains an elongated area of skewness greater than 0.5 and less than 0.8. The central and upper right parts of the triangle are occupied by high positive skewness values. As noted previously, within this area occur the maximum deviations of mean, median, and standard deviation as compared with values derived from a normal frequency function.

APPLICATION OF ESTIMATION METHOD TO WIND DEPOSITED SEDIMENTS

Whereas the preceding discussion was concerned with the relationships among Inman's size parameters computed for water deposited sediments and those estimated from a composition triangle, the estimation method appears to be applicable also to sediments deposited by eolian action. Table 6 contains size parameters computed for twenty-one Pleistocene loess samples from North America and Europe. The basic data for the computations were obtained from a paper by Swineford and Frye (1955). The size parameters of table 6 are not comparable with those appearing in the cited reference, because the latter were computed by moment analysis. The correspondence between Inman's parameters of these

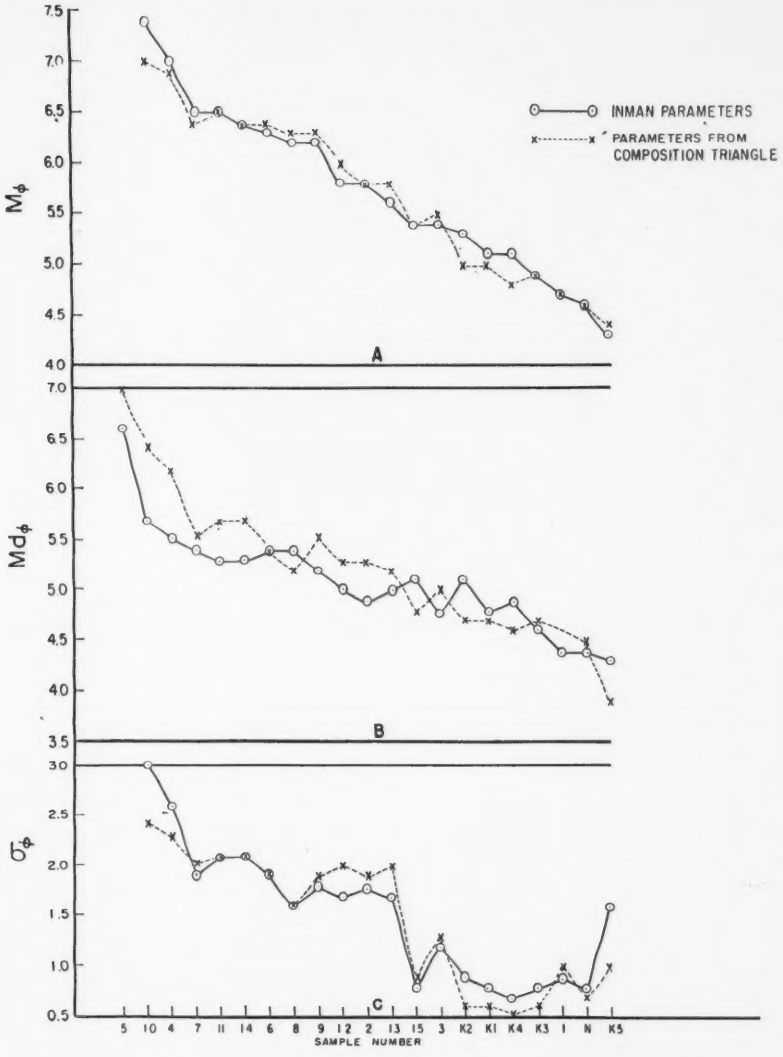

FIG. 8.—Relationship among size parameters computed by method of Inman and estimated from composition triangle. Pleistocene loess (Swineford and Frye, 1955).

TABLE 6.—*Size parameters of Pleistocene Loess from North America and Europe (After Swineford and Frye, 1955)*

Sample	Phi Mean		Phi Median		Phi Deviation Measure	
	M_ϕ[1] (comp. Δ)	M_ϕ[2] (Inman)	Md_ϕ[1] (comp. Δ)	Md_ϕ[2] (Inman)	σ_ϕ[1] (comp. Δ)	σ_ϕ[2] (Inman)
1 Italy	4.7	4.7	4.6	4.4	1.0	0.9
2 Italy	5.8	5.8	5.3	4.9	1.9	1.8
3 France	5.5	5.4	5.0	4.8	1.3	1.2
4 France	6.9	7.0	6.2	5.5	2.3	2.6
5 France[3]			7.0	6.6		
6 France	6.4	6.3	5.4	5.4	1.9	1.9
7 Germany	6.4	6.5	5.5	5.4	2.0	1.9
8 Germany	6.3	6.2	5.2	5.4	1.6	1.6
9 Germany	6.3	6.2	5.5	5.2	1.9	1.8
10 Germany	7.0	7.4	6.4	5.7	2.4	3.0
11 Germany	6.5	6.5	5.7	5.3	2.1	2.1
12 Germany	6.0	5.8	5.3	5.0	2.0	1.7
13 Germany	5.8	5.6	5.2	5.0	2.0	1.7
14 Germany	6.4	6.4	5.7	5.3	2.1	2.1
15 Belgium	5.4	5.4	4.8	5.1	0.9	0.8
N Nebraska	4.6	4.6	4.5	4.4	0.7	0.8
K1 Kansas	5.0	5.1	4.7	4.8	0.6	0.8
K2 Kansas	5.0	5.3	4.7	5.1	0.6	0.9
K3 Kansas	4.9	4.9	4.7	4.6	0.6	0.8
K4 Kansas	4.8	5.1	4.6	4.9	<0.6	0.7
K5 Kansas	4.4	4.3	3.9	4.3	1.0	1.6

[1] Estimated from composition triangle.
[2] Computed after method of Inman (1952).
[3] Distribution curve not definitive at 84 percentile.

samples and those obtained from the composition triangles is shown in figure 8. The samples are arranged from left to right in order of decreasing values of M_ϕ (Inman values). Although these data from eolian sediments were not used in construction of the composition triangles, the parameters obtained by the two methods are in close agreement. Thus, the estimation method of size analysis appears to be applicable to sediments deposited by eolian action as well as by water action.

SUMMARY AND CONCLUSIONS

A simple analytical procedure exists whereby Inman's sediment size parameters of median, mean, deviation measure, and skewness may be estimated from a three-component plot of sand, silt, and clay percentages. The three-component analysis is made easily by abbreviated size analysis methods, and the size parameters are obtained graphically from the three-component plot.

Conversely, if the median and deviation measure of a sediment sample are known, the composition of the sediment may be obtained in terms of percent sand, silt, and clay. Thus, a specific combination of median size and sorting is diagnostic of a specific sand-silt-clay composition.

Because of the interdependence of these two types of data, it appears that for many uses, an expression of sediment size data in terms of sand-silt-clay composition will be sufficient. For those who find it more convenient to use size parameters, such as the median and deviation measure to characterize sediment size composition or who wish to compare new data with those published in terms of Inman's parameters, these data may be

obtained easily from the three-component plot. Of first order importance, however, is the recognition of the interdependence of the two types of data.

ACKNOWLEDGEMENTS

The authors are indebted to Professor K. O. Emery of the University of Southern California for furnishing unpublished size data from Recent sediments of the West Coast and to Mr. D. Poole and Professor F. P. Shepard of Scripps Institution of Oceanography for supplying similar data from the Gulf of Mexico.

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FIGS. 1–5, JUNE, 1956

NOTES

SOIL BOULDERS IN THE TEMECULA ARKOSE

JOHN F. MANN, JR.
University of Southern California, Los Angeles, California

The Temecula arkose is a continental sedimentary formation of lower Pleistocene age which has been preserved by graben-faulting within the Elsinore fault zone in southern California. The exposures may be seen along State Highway 71 about nine miles east of Temecula, which is about 90 miles southeast of Los Angeles. Although this formation consists primarily of white to pale-buff arkose, there are also buff to brown poorly indurated siltstones, white to pale-gray silicified algal marls, and a few beds of white rhyolitic tuff. In the basal few hundred feet, which is almost entirely arkose, the intermittent nature of the deposition is shown by the development of soil zones at numerous stratigraphic levels. These soil zones can be detected only in road cuts and stream-cut cliffs. Poor exposures, repetitious lithology, and intense middle Pleistocene tilting and faulting are factors rendering impossible the detailing of stratigraphic relationships. The various lower Pleistocene soil zones are all very similar in appearance, and are much the same as the soil zones now forming on the arkose. In a few places the old soil zones were removed during scour-and-fill processes (fig. 1). These scour gullies in the Temecula arkose were widened as large masses of the soil zones slumped. Despite the lack of induration of the soil masses, they are

FIG. 1.—Soil zone in the Temecula arkose showing scour-and-fill.

FIG. 2.—Soil boulders in tilted Temecula arkose.

preserved in the arkose beds in large pieces—up to 5 feet across. Many of the larger masses are quite angular and apparently have moved but little from the original positions assumed at the time of slumping. The smaller masses, most of which are of cobble size, have been somewhat rounded (fig. 2). The same process of slumping, with burial of the slumped soil masses, can now be observed, suggesting perhaps that climatic and depositional conditions are much the same now as in Temecula time.

LOWER LIMITS TO THE *So* COEFFICIENT

WILLIAM F. TANNER
Florida State University, Tallahassee, Florida

Trask (1932) considered that any sediment having a sorting coefficient (*So*) smaller than 2.5 was well-sorted. In more recent years it has been shown that *So* values such as 1.09 (Emery, 1955), 1.15 (Tanner and Mallams, 1950), 1.20 (Baker 1951), etc. (Emery, 1954) are common. It is the purpose of this note to point out that the use of "alternate" screens, plus semi-log paper for plotting purposes, is inadequate for computation of sorting coefficients in this range.

"Alternate" here refers to the Udden scale: 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.062 mm.

For sands sieved through "alternate" screens, and for cumulative frequency data plotted on semi-log paper, 1.20 is an approximate lower limit to the *So* obtainable. $So = 1.20$ represents the steepest possible slope having justification in the plotted points. A steeper slope may be correct for any given sample, but the plot will not indicate this fact. Visual estimation of a steeper slope is entirely without warrant.

For the $\sqrt{2}$ ratio screen set, 1.10 is an approximate lower limit to the *So* obtainable. For the $\sqrt[4]{2}$ ratio screen set, the approximate lower limit is 1.05.

Obviously, one solution is to use the full set of screens, as recommended by Twenhofel and Tyler (1941). Another solution is to plot the cumulative frequency curve on log probability paper before picking quartiles and calculating *So*. (For *phi* calculations, arithmetic probability paper should be used.) Values of *So*, under such conditions, approach lower limits at approximately 1.10 for "alternate" screens, 1.05 for the $\sqrt{2}$ ratio set, and 1.025 for the $\sqrt[4]{2}$ ratio set.

It is probable that, especially for *So* based on quartiles picked from semi-log paper, considerable error is introduced at points higher than the approximate limits given above. The general limits below which operations cannot be justified may be summarized as follows:

Screens	*So*	
	Semi-log Paper	Log-prob. Paper
"Alternate"	1.20	1.10
$\sqrt{2}$ ratio	1.10	1.05
$\sqrt[4]{2}$ ratio	1.05	1.025

Log probability paper has at least two additional advantages over semi-log paper for plotting cumulative frequency curves. First, the validity or significance of the work may be questioned for all curves which do not plot as or reasonably close to straight lines. A break or curve may indicate a mixing of samples from different environments, an error in sampling, a change in technique, contamination of the sample, or some other factor. Second, the slope of the straight line is proportional to the value of *So* (Pettijohn, 1949). A perfectly horizontal line indicates $So = 1$. A set of approximate values for *So*, taken from slopes plotted on Codex Book Company Paper 3128, follows:

0°	1.00	45°	1.83
5°	1.11	50°	2.01
10°	1.13	55°	2.2
15°	1.17	60°	2.6
20°	1.23	65°	3.2
25°	1.31	70°	4.5
30°	1.41	74°	7.
35°	1.53	76°	10.
40°	1.67		

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ESTIMATION OF PERCENTAGES IN THIN SECTIONS—CONSIDERATIONS OF VISUAL PSYCHOLOGY[1]

JOHN ELIOT ALLEN
New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico

Sets of comparison charts for visual estimation of mineral percentages have been published by Folk (1951) and recently by Terry and Chilingar (1955) after Shvetsov. All four authors have failed to take into account several basic principles of visual psychology which may seriously affect accurate comparison between such charts and actual thin sections.

Contrasted particles may seem larger or smaller (and hence percentages may be over- or under-estimated) depending upon the predominant background shade. Hence in dealing with black and white cards, the set should extend beyond 50 percent black and up to 90 percent; there should be another set with white particles upon a black background. Use of a neutral gray instead of a strongly contrasting white or black background results in visual estimates that differ considerably from estimates made on the contrasting sets. In addition, the relative size, shape, and distribution of grains in the thin section may also produce errors in estimation. If there are a few large grains, their area tends to be underestimated as compared with the same percentage of grains which are small and evenly distributed over the field.

The reader might test himself by estimating either the actual or relative percent of grains in each of the six circles of figure 1. The answers follow the references.

There are psychological laws involving color contrasts which are just as effective in promoting erroneous estimates. These are too involved to go into here.

Thirty years ago, such sets were used in teaching petrology at the University of Oregon, and color sets using pale yellow, brown, red, and other colors also supplemented the black, white and gray sets. Students learned to recognize the various psychological distortions, and before the course was over, could "guesstimate" within 5 percent consistently (less than that for small percentages), upon thin sections on which modal analyses had been made with recording micrometer stage.

The above suggests another hybrid field of investigation in these days of geophysics, geochemistry, and micropaleobiogeochemistry; perhaps a research problem involving cooperation between visual psychologists and geologists would benefit not only petrography but field geology as well.

[1] Published with permission of the Director, New Mexico Bureau of Mines and Mineral Resources.

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All circles contain twenty-five percent grains.

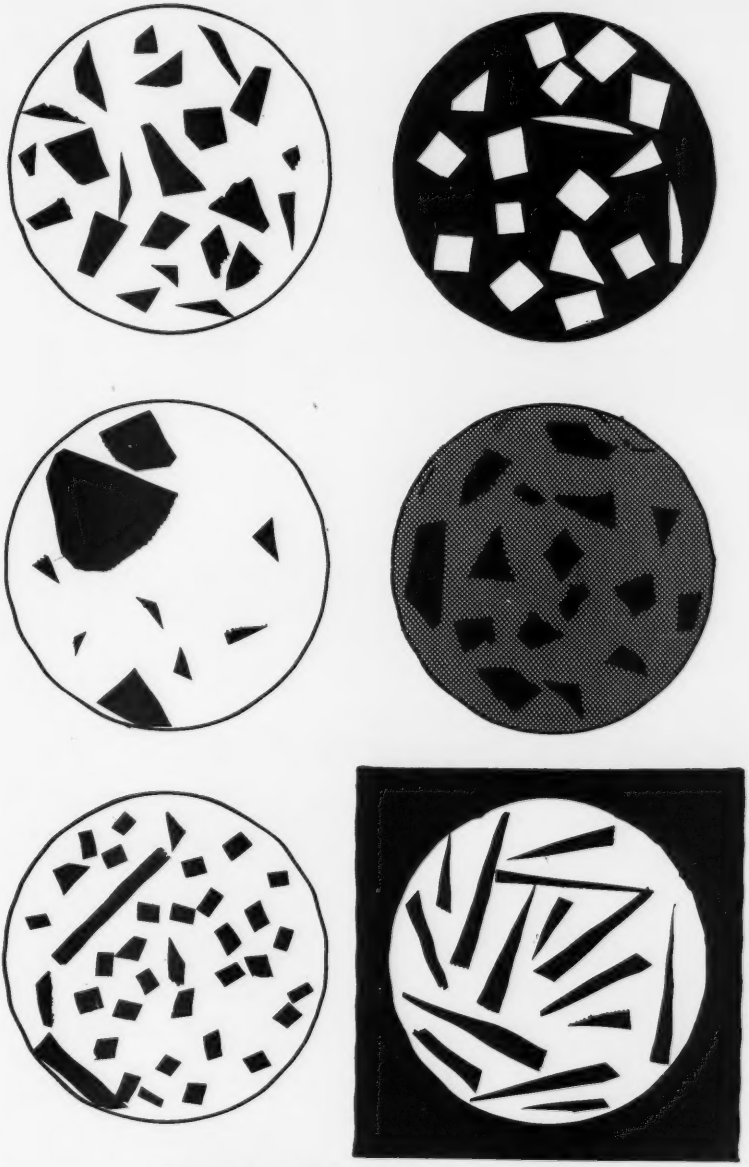

FIG. 1.—Chart for visual estimation of percentage.

A HAND AUGER FOR BORING RECENT SEDIMENTS

JAMES P. MORGAN AND WILLIAM G. MCINTIRE
Louisiana State University, Baton Rouge, Louisiana

For the past four years the Coastal Studies Institute of the School of Geology at Louisiana State University has been conducting field work in the coastal marsh and swamplands of Louisiana, New England, and North Carolina for the Office of Naval Research. An area of approximately 15,000 square miles of Recent sediments has been studied in considerable detail. Thousands of shallow (10–40 foot) hand auger borings have been made for the purpose of sampling and studying the near-surface sediments. After considerable experimentation with conventional soils-type augers a modified type of bit has been developed which is very satisfactory. It is hoped that this piece of equipment may be useful to others working with soft, unconsolidated Recent sediments.

TYPES OF AUGERS USED

1. Bucket-type auger (Post-hole auger)—Fig. 1-a
   - 4-inch diameter
   - 3-inch diameter (smallest obtainable)
2. Conventional soils auger—Fig. 1-b
   - 2-inch diameter
   - 1½-inch diameter
3. Modified power machine bit or ship auger—Fig. 1-c
   - 2½-inch diameter
   - 1¾-inch diameter
   - 1½-inch diameter (best for all-around use)

MODIFICATION OF POWER MACHINE BIT

(1½-inch diameter, 18-inch twist length, round shank)

The bits used for our research were obtained locally from Military Surplus and were manufactured by a company that no longer makes such bits. It is possible that they may be obtained locally from stock in large retail hardware outlets.

Modification of the bit is simple. The ½-inch round shank is welded to convenient length joints of ¾-inch galvanized pipe. The initial cutting edge of the bit is perpendicular to the shaft and must be ground to an angle of approximately 20° in order to have the auger cut satisfactorily into tight clays (fig. 2). The spur, or screw point, should not be removed as it facilitates boring through wood or breaking through shells. The screw point also serves as a guide and helps maintain vertical holes.

MODIFICATION OF SHIP AUGER

(1½-inch diameter, 15-inch twist length, square shank)

The ship auger is a commercial hand tool essentially identical with the power machine bit. It can be obtained by any major hardware retailer. The ship auger is equipped with a square tanged shank, the corners of which must be rounded to obtain a satisfactory weld inside the ¾-inch galvanized pipe. A similar modification (fig. 2) of the initial cutting edge must be made for best field results. This auger is not as satisfactory as the power

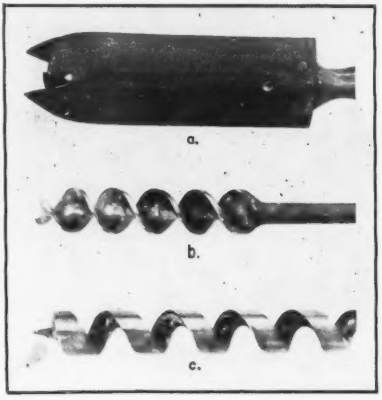

FIG. 1

Comparative characteristics of augers

Auger Type	Characteristics	
	Advantages	Disadvantages
Bucket-type auger, 3-inch diameter	Obtains large sample Retains samples of wet silt and sand better than other augers	More physical labor required than with other types Must core continuously. Cannot be used as a probe Extreme contamination and mixing of thin strata Hard to remove from tight clays Poor cutting characteristics in tight clays and silts Will not cut or break through wood or scattered shells Difficult to clean after sampling
Conventional soil auger, 1½-inch diameter	Good cutting characteristics in tight clays and silts Fair ability to obtain samples retaining contacts between thin strata Easy to clean bit after obtaining sample Sometimes possible to bore or break through small pieces of wood or scattered shells Can be used either for continuous coring or probing	Relatively small sample obtained Sample loss great in soft sediment No recovery of samples of wet silts and sands Sample contamination great in soft or wet clays and fine silts Twist length of bit restricts sampling to ½-foot per "round-trip"
Modified power machine bit or ship auger, 1½-inch diameter	Good cutting characteristics in tight clays and silts Good ability to obtain samples retaining contacts between thin strata Easy to clean bit after obtaining sample Easy to bore or break through small pieces of wood or scattered shells Can be used either for continuous coring or probing Less sample contamination than with other types Twist length of bit allows a 1-foot or 1½-foot sample per "round-trip"	Relatively small sample obtained Sample loss great in wet sands and silts

machine bit because of the shorter twist length. For continuous coring a 12-inch sample is taken with this auger in contrast with an 18-inch sample for the power machine bit.

USE OF POWER MACHINE AUGER OR SHIP AUGER

The modified auger has been used extensively in Recent sediments of coastal Louisiana, Texas, Mississippi, and the New England states. It is particularly adaptable to making borings in silts and clays of natural levees, organic clays and silts of backswamp areas and interlevee basins, and in sections of fresh, brackish, and salt marsh.

Continuous cores have been taken to depths as great as fifty-five feet with the auger but the majority of the borings

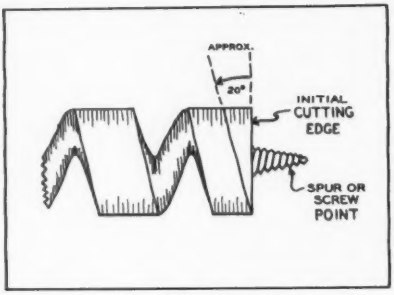

FIG. 2

range from 15 to 30 feet.

Some shallow borings have been made into Pleistocene oxidized silts and clays with satisfactory results but the lower water content of these sediments requires the use of water in the bore hole to lubricate the bit.

Standard weight ¾-inch galvanized pipe is commonly used but is subject to bending in tight material. Extra heavy weight ¾-inch galvanized pipe (weight 1.47 lb/ft vs. 1.13 lb/ft for standard pipe) is recommended for deep holes or tight materials. The pipe is screwed into the ground and removed with the aid of 18-inch pipe wrenches. The new lightweight, aluminum wrenches have proved most satisfactory.

In operation, maximum efficiency can be obtained with parties of three men. Two men can handle the equipment but time is lost when stopping to clean hands and make field notes. For ease in transporting in automobiles, four foot joints of pipe are recommended and in the field connected with standard ¾-inch galvanized couplings. In field operations every other joint is broken and the eight foot pipe sections are used.

THE PREPARATION OF THIN SECTIONS OF WELL CUTTINGS[1]

ROSS HICKAM
Indiana Geological Survey, Bloomington, Indiana

Although petrographic analysis of rocks is a standard well-established method, little has been written concerning the preparation of micro-slides from well cuttings. The problem is mentioned, however, in an article on "Preparation of Thin Sections" by Wagner and Gableman (1950).

In the Preparation Laboratory of the Indiana State Department of Conservation, Geological Survey, located at Indiana University, the following method of preparing slides of small cuttings from wells drilled with either cable tools or rotary rigs has been developed. Since the method is useful, rapid, and economical, it is described briefly for those students and workers who may have need for it. The supplies required for this process are a motor driven lap machine, a hot plate having controlled heat, a heavy glass plate, tweezers, numbers 600 and 303 abrasive powders, Canada balsam, glass slides, cover glasses, xylene, and a diamond pencil.

When starting a slide, 3 to 15 small pieces of good cuttings of the sample are selected. While the hot plate is heating to 120°F the necessary slides, 27×46 mm, can be cleaned and an identification number written on the back of each with a diamond pencil. Several slides are placed on the hot plate at one time, and on them the desired amount of commercially prepared stick balsam is melted. On each slide 3 to 15 cuttings are carefully embedded with the tweezers. After each sample is embedded, the slide is removed and allowed to cool until the balsam hardens. The chips of the slide are then ground on a brass lap at slow speed using a thin paste composed of No. 600 abrasive[2] and water until a flat side is ground on all the chips. The slide is returned to the hot plate to soften the balsam and the chips are then turned over with tweezers so that the flattened side of each is well imbedded in the balsam next to the slide.

Again the slide is removed from the hot plate and allowed to cool until the balsam sets. Grinding is repeated on the second side of the sample, again using the brass wheel at slow speed and a thin paste of No. 600 abrasive and water, until the abrasive can be seen through the sample. A little experience indicates how thin the chips can be ground, but they should be about 0.10 mm at this stage.

A heavy glass plate is then covered with a small amount of No. 303 abrasive powder, made into a thin paste with water. On this plate the sample is ground until it is 0.02 mm in thickness. Moving the sample in a figure eight pattern maintains uniform thickness.

If the sample is to be left uncovered, a razor blade scraper is used to remove excess balsam. If covered samples are required, cover glasses should have been cleaned and placed on the hot plate. A drop of pre-cooked balsam is placed on each cover glass with a glass rod and heated until all the xylene is evaporated. After the sample is rewarmed on the plate, a cover glass is placed over it. The weight of the cover glass will cause the hot balsam to flow and level itself out.

When the grinding is finished and the cover glass is in place, the slide is cleaned with xylene to remove excess balsam and then washed with soap and water to remove the xylene. The samples are then ready for study.

[1] Published by permission of the State Geologist, Indiana Geological Survey.

[2] Although in the normal numbering of abrasives the higher the number the finer the abrasive, this is not the case with these products. Number M303 Centriforce Abrasive (American Optical Co.) is finer than No. 600 Crystolon Abrasive.

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WAGNER, W. R., AND GABLEMAN, J. W., 1950, Micro (petrographic) analysis: *in* Subsurface Geologic Methods, compiled by L. W. LeRoy, Colorado School of Mines, Golden, Colorado, p. 179.

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 26, NO. 2, PP. 166–171
FIG. 1, JUNE, 1956

DISCUSSION

THE ROLE OF TEXTURE AND COMPOSITION IN SANDSTONE CLASSIFICATION

ROBERT L. FOLK
Univerity of Texas, Austin, Texas

In a recent issue of this *Journal* (vol. 25, pp. 201–206) John Bokman considered the question of sandstone classification in relation to mineral composition and texture. In this discussion he supports the viewpoints proposed by Pettijohn (1949), Dapples, Krumbein, and Sloss (1953), and again Pettijohn (1954); but he vigorously criticizes the classification published by this writer (Folk, 1954) in which a ternary basis for rock nomenclature was introduced, including grain size, textural maturity, and mineral composition. Apparently Bokman on p. 201 follows wholeheartedly this writer's four stages of textural maturity (Folk, 1951) —although he fails to cite the paper in which this classification was proposed— and he also agrees fully that clay content should be considered a textural and not a compositional property. Furthermore, Bokman adopts a mineralogical classification essentially similar to that proposed by this writer (1954), and also like those suggested by Krynine (1948) and Dapples, Krumbein, and Sloss (1953).

Bokman's only major criticism of this writer's classification thus comes down to (1) what shall we call the rock types formed by combination of the three compositional end-members with the four stages of textural maturity, and (2) what is the extent of variation from an alleged "main sequence" of sandstone types— the hypothesis of a "main sequence" that supposes that texturally immature sediments are nearly all rich in feldspars or metamorphic rock fragments ("crushed rock complex" of Dapples, Krumbein, and Sloss), while texturally mature and supermature sediments are almost always nearly pure quartz or chert.

Before discussing the two arguments above in more detail, I would like to consider first the concept of textural maturity and its relation to tectonism versus environment. Bokman sets up three highly idealized environmental groups of sandstones based on the presence of three "energy levels" existing at the site of deposition, with the resulting sediments possessing three (or really four) stages of textural maturity. According to Bokman, these are (1) the undisturbed environment, supposedly typical of rapid burial in geosynclines and characterized by sands rich in clay (immature stage of Folk); (2) partially reworked zone, occurring on unstable shelves and intracratonic basins, and characterized by essentially clay-free but still poorly-sorted sediments (submature stage of Folk); and (3) intensely reworked zone, typical of stable shelves and marked by well-sorted sands (mature stage of Folk), with the most stable shelves also having well-rounded sands (supermature stage of Folk).

When this writer first published the idea of textural maturity, he also attempted to tie it up with the rate of subsidence of the basin of deposition, hence tectonic activity. Now, however, he realizes that this was a naïve oversimplification and that textural maturity is much more a function of local environment rather than overall tectonism, especially in the lower stages of maturity. A flood-plain or neritic sediment will probably contain just as much clay if the depositional basin is sinking at the rate of one inch per hundred years, or one inch per ten thousand years. Similarly, a sample of beach sand will get just

as well sorted in one hundred years (or even in a few weeks) as it will if given one hundred thousand years. Texas Gulf coast beaches (and their buried Tertiary equivalents) have excellent sorting values, with σ in the range of 0.25–0.35 ϕ; yet I daresay no one would call this region a "stable shelf." One swish of a miner's pan does a pretty good job of sorting sand, and certainly of winnowing out clay; hence no long period of stability is required to get well-sorted sediments, and good sorting cannot be equated with tectonic stability as Bokman has done now, and as the writer did in 1951. Only in roundness does tectonism have much to do with textural maturity, and even here it has much less influence than commonly thought. Sands in the carbonate sequence of the Ellenburger group (Ordovician of subsurface West Texas) show a repeated alternation of streaks of angular sands with beds of superbly rounded sands of the same grain size, all coming directly from the same primary granitic and gneissic source area; if periods of tectonic stability are called upon to explain the beds of well-rounded sand, then these stable periods must have each covered only a minute fraction of the Ordovician. Similar brief stable periods are indicated for the Silurian sands of West Virginia, where beds of perfectly rounded grains alternate with beds of angular grains, all coming from the same source area. In the opinion of this writer, the alternations are caused by fluctuating environments and are modified only slightly by tectonism.

Although the environment of deposition is apparently the immediate controlling factor in textural maturity, the environments themselves are a function of something much more basic. As Krynine (1951) has shown, the degree and type of tectonic activity does determine a certain preferred association of source area lithology and relief, geomorphic processes, and rate of subsidence of the depositional area. These factors in turn integrate to produce preferred associations of environments: during a period of stability beach sands will be abundant in the section, and deltaic sediments scarce; while during a period of intense geosynclinal deformation deltaic and neritic sediments will be very abundant and beach sands scarce. Yet beach sands deposited in both tectonic frameworks will have essentially similar sorting values, and neritic sediments will be just as immature.

Bokman also errs when he equates clayey sandstones with the undisturbed (presumably deep-water) environment "typical of the eugeosyncline." Admittedly, clayey sands develop when very little energy is expended on the sediment after its initial deposition, but this situation can happen in numerous ways. Not only does it happen in deep waters, but it also happens in mudflows, many alluvial fans, flood plains, swamps, lagoons, deltas, and is probably characteristic of most neritic sands along normal coasts. Shall these all be glibly considered eugeosynclinal deposits? Furthermore, on page 202 he implies that most of these clayey sands are deposited by turbidity currents! Until the precise mode of deposition of clayey sands is supported by more concrete data from recent sediments, I contend that most clayey floodplain and neritic sands in all but quite deep waters are simply deposited by ordinary sedimentation, where clay brought out to sea by muddy rivers or set in motion by wave turbulence simply settles by some quite "normal" mechanism. By extension of the overworked turbidity current hypothesis, should we assume that all clays and shales are deposited by this process in eugeosynclinal loci? Of course not—hence if clays and shales can form by ordinary processes of deposition, then clayey sands can also form this way.

My present feeling on maturity is that (1) it depends chiefly on the amount of energy applied to the sediment *after* it is brought to the site of deposition, hence is almost entirely a function of environment and is virtually independent of tectonism. Even in the most violently subsiding basins the rate of subsidence is so slow in inches per year that the environ-

TABLE 1.—*Sandstone classification table based on the two parameters of textural maturity and mineral composition. Folk's (1954) terms in ordinary type, corresponding terms of Bokman (1955) in italics. Asterisks denote rock types not recognized by Bokman but considered to be of great importance by Folk*

State of Textural Maturity	Feldspar-Rich Sands	Quartz- and Chert-Rich Sands	Metamorphic-Rich Sands
Quartz grains well rounded, well sorted, no clay	Supermature Arkose * * * * *	Supermature Orthoquartzite *Orthoquartzite*	(Supermature Graywacke) * * * * *
Grains well sorted, no clay, but not well rounded.	Mature Arkose * * * * *	Mature Orthoquartzite *Orthoquartzite*	Mature Graywacke * * * * *
Very little or no clay, but grains poorly sorted.	Submature Arkose *Arkose*	Submature Orthoquartzite * * * * *	Submature Graywacke *Lithic Sandstone*
Over 5 percent clay, poorly sorted, and angular.	Immature Arkose *Arkose*	Immature Orthoquartzite * * * * *	Immature Graywacke *Lithic Sandstone*
Over 20 percent clay, poorly sorted, and angular.	Immature Arkose *Feldspathic Graywacke*	Immature Orthoquartzite * * * * *	Immature Graywacke *Lithic Graywacke*

ment has ample opportunity to modify the detritus; (2) a surge of excess energy can actually decrease the maturity of a sediment (as when hurricane winds mix well-sorted beach sands with almost pure lagoonal clays to form a very poorly sorted mixture, or when sudden mountain torrents shatter pebbles that were previously rounded by more gentle streams); and (3) stratigraphic formations all show a range in maturity on the individual sample level; hence, in many formations clayey sands alternate with well-sorted sands. I would hardly call this an alternation between eugeosynclinal and stable shelf conditions when the change soccur on the scale of a foot or so!

Bokman's first major criticism of my classification is in the names applied to the rocks resulting from the various combinations of textural maturity with mineral composition. I feel that names should be subordinated to concepts, so that if the principles of formation are understood and the petrographer publishes adequate detailed descriptions, anyone is entitled to give any name he pleases to the rock under consideration. However, I earnestly defend the proposition that textural maturity and mineral composition should be described in separate terms to avoid confusion and overgeneralization. Bokman states on pp. 201–202, that "Composition and texture are interdependent properties . . . consequently, they are not susceptible to separate treatment"; yet in the three paragraphs immediately preceding this statement, he treats these properties independently himself. The differences in the nomenclature are indicated in table 1 with my terms in ordinary type and Bokman's terms in italics. For brevity, only the end-members are shown here; rocks rich in both metamorphic rock fragments and feldspars are omitted, as are transitional types between the orthoquartzite and the two other end-members. Thus Bokman's "protoquartzite" occupies the field on either side of the orthoquartzite in the immature to submature range, and my "subarkose" and "subgraywacke" occur also on each side of the orthoquartzite, but exist (in nature as well as in theory) in all stages of textural maturity. The asterisks denote rock types apparently not recognized or specified by Bokman.

Contrary to the statements of Bokman (as reflected also in his lack of a complete set of terms), all these "pigeonholes" are occupied by significant volumes of rock in the stratigraphic section with but one exception: the supermature graywacke which may well be a nonexistent type. The question of which scheme is more logical should now be left to the judgement of time; I have previously listed (Folk, 1954, pp. 352–356) my reasons for objecting to the use of the term graywacke as a synonym for a clayey sandstone and will not go into those reasons again here.

Two minor points which come up in allotting rock constituents to the Q, F, or M poles: (1) I specifically *excluded* clays from the mineralogical triangle in three separate statements (Folk, 1954, pp. 352, 353, 355), although Bokman on page 205 distinctly states that I *included* it with the metamorphic pole. I did include with the M pole all coarse-silt size grains of chlorite, sericite, and other fine micas, for a very practical reason: since micas are included with the M pole, it is fatuous hairsplitting to draw any distinct line between the finer micas and the silt-sized sericite or chlorite. Bokman sidesteps this slight difficulty by not mentioning micas at all in his classification. (2) In most good graywackes there is a complete transition between fragments of schist, quartzose schist, micaceous metaquartzite, and "pure" metaquartzite; here no one would question allotting stretched metaquartzite to the M pole. If one is to be consistent, metaquartzite is a metamorphic rock fragment and should be counted as such whether in a polar graywacke or an almost pure orthoquartzite. Rock descriptions should not be bent to conform to our preconceived notions of how the rock should be classified.

Bokman's most fundamental argument against the classification of this writer is in the relationship between the two variables, textural maturity and mineral composition. He assumes the same grossly overgeneralized hypothesis proposed by Dapples, Krumbein, and Sloss (1954): namely, that immature and submature sediments must be rich in feldspars or metamorphic rock fragments, and that mature and supermature sediments must consist almost entirely of quartz and chert. Bokman implies that mineral composition and textural maturity are incapable of independent variation, and that no samples occur outside of this "main sequence." To quote: "To treat [composition and texture separately] . . . leads to a classification which is meaningless in the sense that many of the 'pigeonholes' are unoccupied in actuality. . . ." I contend that the close linkage between composition and texture proposed by Dapples, Krumbein, and Sloss and restated by Bokman is far too idealized to fit the actual situation. They attempt to force sediments into a rigidly artificial mold to which they simply will not conform, as any examination of an adequate thin-section collection will show. On page 205 Bokman indirectly attacks Krynine (without mentioning his name) for oversimplifying the linkage between tectonism and mineral composition, but throughout his entire paper Bokman falls into the very same alleged error by assuming a direct and vastly oversimplified link between tectonic state, textural maturity, and mineral composition—a linkage apparently so tenuous that he presents no evidence, either from the stratigraphic column or from recent sediment work, to back it up.

I agree that most sediments do tend to follow the main sequence—i.e. that immature graywackes, as they undergo more and more abrasion, tend to pass up the scale of maturity as they lose their less durable metamorphic constituents and eventually pass through subgraywackes into orthoquartzites. Similarly, arkoses, either through abrasion or weathering, tend to lose their feldspar as they pass up the scale of maturity and grade into subarkoses and ultimately orthoquartzites. Yet, the fundamental difference is that Bokman feels that rocks falling on the main sequence are the *only* ones worthy of classification, whereas I have examined (and cited—Folk, 1954,

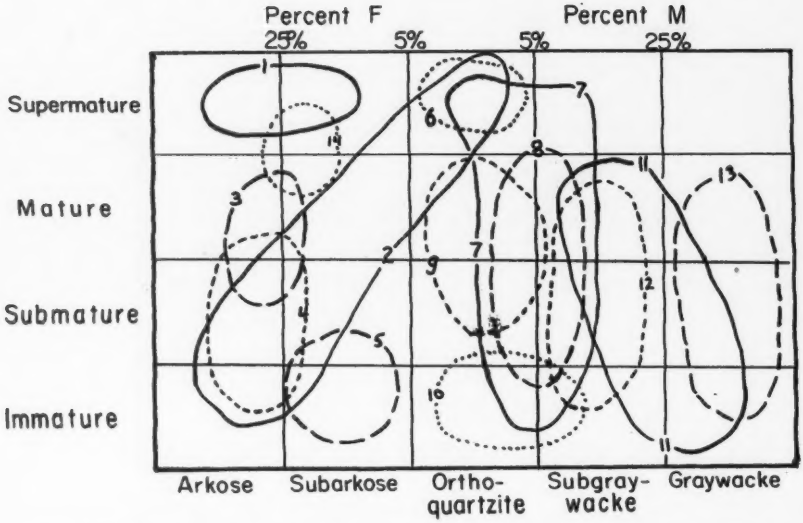

FIG. 1.—Mineral composition plotted against textural maturity for several sandstone formations. This diagram illustrates that almost any combination of the two variables may occur. According to other authors, sediments occur almost entirely on the "main sequence," extending in an inverted V-shaped trend from the immature arkose to the mature or supermature orthoquartzite, and back down to the immature graywacke. The "main sequence" hypothesis is clearly a profound oversimplification.

1. Lower Ordovican Beekmantown sands, Pennsylvania. Folk, manuscript in preparation. This field also applies to Upper Cambrian, Pennsylvania.
2. Lower Ordovician Ellenburger sands, Texas. Folk, manuscript in preparation.
3. Upper Permian (?) Pierce Canyon formation, Texas and New Mexico. D. N. Miller, Ph. D. Thesis, University of Texas, 1955.
4. Triassic Newark Series, Connecticut. Krynine, 1950.
5. Recent Gulf Coastal sands, Texas. Folk, unpublished observations.
6. Upper Cambrian Potsdam sandstone, New York. Folk, unpublished observations.
7. Silurian System, West Virginia. Folk, research in progress.
8. Cretaceous Woodbine sand, Texas. A. S. Cotera, M. A. Thesis, University of Texas.
9. Pennsylvanian sandstones, central Texas. Folk, unpublished observations.
10. Recent Gulf Coastal sands, Mississippi and Alabama. Folk, unpublished observations.
11. Ordovician Juniata and Oswego formations, Pennsylvania. O. F. Tuttle, M. S. Thesis, The Pennsylvania State College, 1940. An essentially coexistent field is occupied by the Devonian Third Bradford Sand, Krynine, 1940.
12. Eocene Carrizo and Newby sands, Texas. T. W. Todd, M. A. Thesis, University of Texas, 1955.
13. Pennsylvanian sandstones, eastern Pennsylvania. Folk, unpublished observations.
14. Numerous scattered samples of Mesozoic sands, Texas and New Mexico. Folk, personal observations.

p. 355, 357) a great many examples of rocks which fall off this main sequence: perfectly rounded, beautifully-sorted arkoses from the Cambro-Ordovician of the Appalachian area; well-sorted graywackes, rich in metamorphic rock fragments, from the Upper Paleozoic of the Appalachians and Texas; poorly-sorted, angular, clay-rich orthoquartzite sands from the Pennsylvanian of Texas, Silurian of West Virginia, and other localities. These rock types are plotted in figure 1. These important and widespread sandstone varieties occupy the "vacant pigeonholes" which Bokman contends are present in my classification—rock types recognized neither by him nor by Dapples, Krumbein, and Sloss. Bokman's compilation of 61 literature analyses (to which no references are given) apparently was not sufficiently comprehensive to include these types.

A fertile analogy may be drawn between sandstone classification and the classification of stars. Astronomers possess a wonderful tool in a graph known as the Hertzsprung-Russell diagram, in which the magnitude (brightness) of a star is plotted against its color, just as I have plotted textural maturity against composition in figure 1. On the Hertzsprung-Russell plot, most stars follow the "main sequence" in that faint stars tend to be reddish and bright stars bluish, the magnitude versus color trend forming a compressed band. But astronomers obtain some of their most vital information by studying the *departures* from this trend, thus using the diagram as a tool in interpreting such stellar types as red giants or in tracing the evolution of star clusters. They do not ignore or fail to classify stars that fall off the main sequence; these unusual ones are precisely the ones that furnish the most valuable clues to the origin of our universe!

Similarly, sedimentary petrographers obtain some of their most valuable information from sandstones that fall off the main trend. Thus well-sorted, well-rounded arkoses are believed to indicate aridity in the source area, for under almost any other climatic conditions the feldspar would have been destroyed by weathering before it had a chance to get rounded. The clayey, poorly-sorted orthoquartzite-type sands also imply specialized conditions: either fairly rapid erosion and deposition of sediments from an area of older sedimentary rock outcrops, or a mixture of several environments, e.g. well-sorted beach sands mixed with lagoonal clays. To ignore these important rock types because they do not follow the theoretical main sequence is to view the complexities of sandstone types with rose-colored glasses. Bokman's connection of tectonic state with textural maturity may be an interesting theoretical exercise, but there are so many exceptions that I seriously question its utility, and even question its ultimate scientific basis. His contention that mineral composition is a direct function of textural maturity is also shown to be erroneous and simplified beyond the point of realism by the specific examples I have cited.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 26, NO. 2, PP. 172–210
JUNE, 1956

SOCIETY RECORDS AND ACTIVITIES

REPORTS AND MINUTES OF THE THIRTIETH ANNUAL MEETING OF THE SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

The thirtieth annual meeting of the Society of Economic Paleontologists and Mineralogists was held in the Waldorf Room of the Conrad Hilton Hotel, Chicago, Illinois, April 23–26, 1956, in conjunction with the annual meeting of the American Association of Petroleum Geologists.

The Presidential Address of the Society "In Defense of Outdoor Geology," was given by Francis J. Pettijohn at the joint session on Tuesday, April 24.

Also at the joint session, an "Honorary Membership Scroll" was presented to Raymond C. Moore, who was elected to Honorary Membership by the Council in December, 1955.

Born at Roslyn, Washington, February 20, 1892, Moore received a B.A. degree from Denison University, Granville, Ohio, in 1913, with major training in the classics and geology; in 1916 he was awarded a Ph.D. (summa cum laude) from the University of Chicago, in geology, with major work in stratigraphy and paleontology. Denison University bestowed an honorary Doctor of Science degree upon him in 1935.

Dr. Moore was State Geologist of Kansas from 1916 until 1954. His teaching experience includes: instructor of geology at Denison University, 1912–13; assistant professor of geology, University of Kansas, 1916–18; associate professor, 1918–19; and professor since 1919. He was chairman of the Department of Geology at Kansas University from 1920 to 1939 and again from 1952 to 1954.

In November and December of 1947, Dr. Moore was a Distinguished Lecturer for The American Association of Petroleum Geologists. His research and writing are chiefly in the fields of stratigraphy, invertebrate paleontology, geomorphology, and regional tectonics. He is the author of several textbooks on Historical Geology and has published approximately 200 articles in scientific journals.

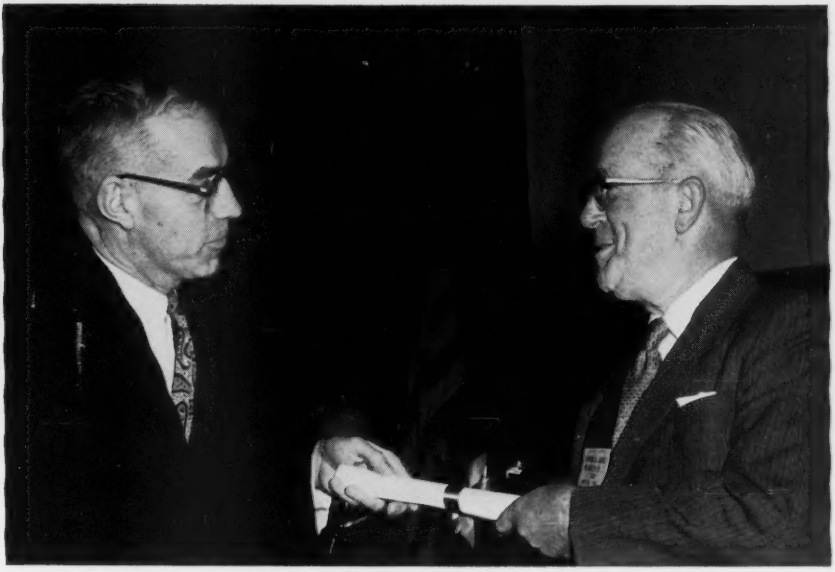
Moore has been editor of the A.A.P.G. *Bulletin* and the S.E.P.M.'s *Journal of Paleontology* and *Journal of Sedimentary Petrology*. Since 1948 he has organized and directed the Treatise on Invertebrate Paleontology. When completed this will include 22 volumes, 5 of which have already been published and 2 are in press.

Among numerous others both U. S. and foreign, Dr. Moore's scientific affiliations include membership in The American Association of Petroleum Geologists (a Founder) and the Society of Economic Paleontologists and Mineralogists (charter member and president in 1928); fellow of the Geological Society of America; member of the Paleontological Society (president in 1927); member of the American Association for the Advancement of Science; and member of the Kansas Geological Society.

In addition to the Honorary Membership Award, Research Committee Chairman, Raymond Siever, presented the Society's Award for the Best Paper for 1954 in the *Journal of Paleontology* to Donald Parkinson, for his paper entitled, "Quantitative Studies of Brachiopods from the Lower Carboniferous Reef Limestones of England," which appeared in the May issue, Volume 28, Number 3. Mr. Siever also presented the award for the best paper for 1954 in the *Journal of Sedimentary Petrology* to Harold N. Fisk, Charles R. Kolb, Edward McFarlan, Jr., and Louis J. Wilbert, Jr. (deceased), for their paper entitled, "Sedimentary Framework of the Modern Mississippi Delta," which appeared in the June issue, Volume 24, Number 2.

The Best Paper Awards are the second to be presented by the S.E.P.M. They consist of a certificate given to the author, or co-authors, whose paper, appearing in the Journals during the second preceding year, is judged by the Research Committee to be the most outstanding contribution of the year.

Donald Parkinson is a native of Clitheroe, Lancashire, England. He entered Birmingham University in 1919 where he graduated with first-class honors in geology. He obtained the Ph.D. degree from Birmingham in 1925 and the D.Sc. degree in 1936. After



RAYMOND C. MOORE (right) receiving honorary membership certificate from S.E.P.M. President Pettijohn.

DONALD PARKINSON

BEST PAPER AWARD, 1954

Journal of Paleontology

HAROLD N. FISK

CHARLES R. KOLB

EDWARD MCFARLAN, JR.

LOUIS J. WILBERT, JR.

BEST PAPER AWARD, 1954
Journal of Sedimentary Petrology

serving on the geological staff at Queen's University, Belfast, Ireland, from 1925 to 1927, he joined the Dunlop Rubber Company. In 1937 he was awarded the Wollaston Fund by the Geological Society in recognition of his research. In 1953 he was awarded the highest award of the Institution of the Rubber Industry, the Colwyn Medal, for conspicuous scientific and technical services to the Industry. Retiring from the Dunlop Rubber Company in August, 1955, he is now a consultant with the United Carbon Company of Charleston, West Virginia. Dr. Parkinson is an honorary associate of the Birmingham College of Technology, a fellow of the Institute of Physics, and a member of the American Chemical Society.

Harold N. Fisk was born in Medford, Oregon. He obtained his B.A. and M.A. degrees from the University of Oregon in 1930 and 1931 respectively. In 1933 he was granted a Ph.D. in petrography from the University of Cincinnati. His early experience includes research and teaching at the University of Oregon, University of Cincinnati, Northwestern University, and Louisiana State University. In 1935 Fisk joined the faculty of L.S.U., a position he held until 1948 when he became chief geologist, research section, for the Humble Oil and Refining Company in Houston. Dr. Fisk has been a consultant for the Mississippi River Commission since 1941 and was a research geologist for Louisiana Geological Survey from 1935 to 1940. He is a fellow of the Geological Society of America, a member of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists (president, 1953–1954), American Geophysics Union, and the American Society of Civil Engineers.

Charles R. Kolb is a native of Vicksburg, Mississippi. Except for short courses at George Washington and Purdue Universities, his geologic education was received during the years 1937–39 and 1947–49 at Louisiana State University (B.S. in geology in 1948 and M.S. in 1949). He spent one year, 1949–50, with the Snare Engineering Corporation, a consulting engineering firm, on ground-water and dam construction problems in Chile. Except for this period Kolb has worked almost continuously, since 1946, on a part- or full-time basis with the Geology Branch, Waterways Experiment Station, a research laboratory of the Corps of Engineers located at Vicksburg. At present his official title is Chief, Geology Branch, Soils Division. Professional associations include: Fellow of the Geological Society of America, associate member of the American Association of Petroleum Geologists, member of Sigma Xi and the Vicksburg Engineers' Club. Sedimentary processes in alluvial and deltaic environments and their application to engineering problems is his principal field of endeavor. However, his work also involves evaluation of terrain features for military purposes, airfield site selection, and aerial photo interpretation of soils for engineering purposes.

Edward McFarlan, Jr. was born in Brooklyn, New York. His undergraduate work was completed at Williams College in 1943. In 1948, he received a Master of Arts degree from the University of Texas, where he held the Shell Oil Company fellowship during the year 1947. In 1948 he accepted a position with the Humble Oil and Refining Company, Houston, Texas, and is currently conducting research in Quaternary geology. McFarlan is co-author of a paper, "Late Quaternary Deltaic Deposits of the Mississippi River," in the Crust of the Earth, G. S. A. Special Paper 62, 1955. Membership in scientific societies includes the Society of Economic Paleontologists and Mineralogists, The American Association of Petroleum Geologists, and the Geological Society of America.

Louis Joseph Wilbert, Jr., consulting geologist, died March 17, 1953, as the result of injuries sustained in an automobile accident near Opelousas, Louisiana. He was born in Plaquemines, Louisiana, October 21, 1919. He attended Spring Hill College in Mobile, Alabama, for one year, transferring to Louisiana State University in the fall of 1937 to work toward a B.S. in geology. Requirements for the Bachelor of Science were completed in June, 1940, and a Master of Science degree was conferred on him in June, 1942. After his release from the army in 1946, Wilbert began study toward a doctorate at the University of Kansas. The degree of Doctor of Philosophy was conferred on him in June, 1951. Wilbert served as a teaching assistant at Kansas University

and an instructor at L.S.U., later being promoted to assistant professor on the Louisiana State University faculty, and retained that rank until his resignation in 1952 in order to devote most of his time to consulting work. He was appointed a co-editor of the *Journal of Paleontology* for the year 1952. Among other organizations, Wilbert was a member of the Geological and Mining Society of American Universities, American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, Geological Society of America, and American Geophysical Union.

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

30th ANNUAL MEETING

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PROGRAM AND ABSTRACTS

Monday, April 23, 1:45 P.M.

Grand Ballroom, Hilton Hotel

RESEARCH COMMITTEE SYMPOSIUM

"DIRECTIONAL PROPERTIES OF SEDIMENTARY ROCKS"

Presiding: RAYMOND SIEVER, University of Illinois, Urbana, Illinois, AND CURT TEICHERT, U. S. Geological Survey, Denver, Colorado

1. INTRODUCTION

RAYMOND SIEVER
Illinois State Geological Survey, Urbana, Illinois

2. FLUME EXPERIMENTS ON THE PRODUCTION OF STRATIFICATION AND CROSS-STRATIFICATION

EDWIN D. MCKEE
U. S. Geological Survey, Washington, D. C.

Experiments are being conducted in flumes designed to simulate conditions of deposition (1) through stream current action, (2) by slumping into a standing body of water, and (3) under the influence of wave action. Previous experiments, made in a wind tunnel with dry sand, formed deposits (1) by wind currents and (2) by avalanching down steep slopes. Deposition, stratification, or cross-stratification was developed under each of the five environments. The type of deposit formed depends upon such factors as speed of current, depth of water, size of grain, degree of sorting.

Significant observations from the experiments include: (1) Foreset beds develop without bottomset beds where sorting is good and clay minerals are absent or sparse. (2) Topset beds commonly are eliminated in delta-front deposits through lowering of the water level. (3) Wind-deposited sand on the lee sides of dunes forms strata with dips that consistently are several degrees greater than those of foreset slopes in water-deposited sand of corresponding grain size and texture. (4) Channel profiles tend to be U-shaped where formed by streams flowing down the channel bottoms, semicircular where formed by currents in a standing body of water that fills the channels. (5) Cross-stratification that appears to be upside down, consisting of festoons that are convex upward, can be formed by coalescing lobes at the front of an advancing delta; strata in channelfills, including "festoon" types, vary from those that curve in conformity with the channel to those that are nearly flat-lying as a result of differences in position of water level at or above the channel rims during deposition.

3. SAND-GRAIN ORIENTATION AND GEOLOGICAL APPLICATION

GENE A. RUSNAK
Scripps Institution of Oceanography, La Jolla, California

Theoretical considerations based on the laws of fluid mechanics indicate that the most stable position which an ellipsoidal particle acquires in depositional transport is one in which the long axis lies parallel to the direction of fluid motion, and with a slight dip into the current. Results of an experiment reveal that although large perturbations exist in the process of sedimentation, the theory is valid in a statistical sense. Throughout the study, statistical tests are used for determining the preferred direction of orientation and the degree of orientation.

The reliability of sand-grain orientation, as a means of determining transport direction, is tested in a geological situation containing rigid directional control. The control used in this test is the cross-bedding dip directions of the Mansfield sandstone of western Indiana. A hierarchical sampling design was used in collecting field samples for testing the variability of grain orientation at several levels of sampling. The variance components of grain-orientation direction we then compared with the variance components of cross-bedding dip direction. These results demonstrate the degree of reliability which may be expected in using grain orientation direction as an indicator of sediment transport direction. Conclusions of the study indicate the usefulness of grain orientation as a geological tool.

4. GRAIN ORIENTATION STUDIES OF RECENT SANDS

JOSEPH R. CURRAY
Scripps Institution of Oceanography, La Jolla, California

Grain orientation measurements have been made on oriented thin sections of artificially lithified sands collected from a variety of modern environments. The results of the study have established the existence of a preferred orientation direction of the long axes of the sand grains parallel to the direction of the depositing current. Each environment has shown a characteristic orientation pattern. Statistical methods have been used to express and evaluate the results of all measuremnts.

Sands from a beach foreshore and the wave-washed part of the berm show a preferred orientation direction parallel to the backwash direction of the waves. This direction is approximately perpendicular to the shoreline, although strong longshore currents may cause some deviation. Samples from dunes and the dry part of a beach may be individually well oriented, but show large sample-to-sample variation because of fluctuation in wind direction. Other beach subenvironments have also been investigated.

The preferred orientation direction of a composite of samples collected at random from the narrow abandoned beach ridges, or chenieres, of southwestern Louisiana is approximately perpendicular to the trend of the sand body. The wind-deposited samples tend to mask this preferred orientation, but the consistent good orientation of the wave-washed samples is generally strong enough to produce a statistically significant composite preferred orientation. In contrast. sands from river-sand bars and channel fills show a preferred orientation parallel to the trend of the sand body.

The following applications of sand-grain orientation are suggested:

1. To predict the trend of an elongate sand body, knowing its origin.
2. To determine the origin of an elongate sand body, knowing its trend.
3. To detect the presence and direction of a current depositing or reworking a sand.

5. DIRECTIONAL PROPERTIES OF SOME CALIFORNIA SANDSTONES

L. C. BONHAM
California Research Corp., La Habra, California

Fabric studies of a number of Upper Miocene and Pliocene sandstones of Southern California revealed several directional properties of the sediments and provided logical explanations of their origin. Preferred dimensional orientations that occur in both deformed and undeformed rocks cannot be attributed to rolling or stretching after deposition; therefore, they must be the result of depositional processes. Similarly, crystallographic orientation of quartz in the same rocks is also related to depositional processes by a consideration of the relationships between quartz-grain elongation and crystallographic axes.

Another directional property is velocity anisotropy which, in the samples studied, is correlated with preferred orientation of microfractures.

6. ORIENTED PHENOMENA PRODUCED BY SEDIMENTATION FROM TURBIDITY CURRENTS AND IN SUBAQUEOUS SLOPE DEPOSITS

JOHN E. SANDERS
Yale University, New Haven, Conn.

Turbidity currents may produce structures and fabrics having preferred orientation: (1) by reaction with the bottom prior to deposition of their load, (2) in the process of deposition, or (3) by tractional reworking of the material they deposit.

Flow marks (Generally preserved as flow casts [or flute casts]) and drag marks (generally preseved as groove casts) are formed prior to deposition by the moving turbidity current and record the azimuth and, in certain instances, the direction of the current. These marks closely parallel downslope direction and require a firm substratum for their formation and preservation. A turbidity current may pull up a watery clay substratum into attenuated ripple-like forms which in transverse profile are bent over downcurrent.

As deposition takes place, graded bedding may occur and elongate objects (pebbles, shells, plant fragments) tend to be oriented with long axes parallel to current direction, either by being transported in this position or by rotation after striking bottom on one end. Imbrication of platy pebbles may result; both upcurrent and downcurrent dips have been reported. Material is sorted laterally with coarser pebbles generally remaining near the source in any given bed.

After deposition begins, fabrics previously formed may be realigned by tractional shifting which can cause several kinds of current ripples and ripple cross-lamination. On ripple crests elongate particles tend to be oriented with long axes parallel to current direction; in troughs long axes are perpendicular to current direction. Migration of ripples produces ripple cross-lamination.

Internal orientation of fine-grained particles, however formed, may be expressed as parallel partings on bedding surfaces. These partings are parallel to long axes of oriented grains and may be parallel to turbidity current direction (if the grains were oriented by direct deposition from the current) or perpendicular to current direction (if governed by ripple lamination).

Intricate internal folds within a single bed (convolute lamination, whose origin is as yet unknown) may be oriented with axial planes dipping upcurrent.

Deposits on subaqueous slopes may form structures by mass movement due to sliding or load casting. Sliding may give rise to folds and overthrusts (whose orientation can be used to infer slope direction under favorable circumstances), pull-aparts (sedimentary "boudinage"), or slide marks (sedimentary "slickensides" at contact of sliding mass and substratum, which are oriented downslope). Sedimentary loading over a hydroplastic substratum may induce loadcast phenomena which may or may not have preferred orientation. Elongated load-cast structures formed in turbidity-current deposits tend to parallel current direction.

The geopetal value of these phenomena is not considered.

Most of the features described require outcrop examination to infer current direction, Many of these are not limited to deposits laid down by turbidity currents and resemble phenomena formed in other environments of sedimentation (notably glacial) or by tectonic movements. As turbidity current deposits commonly occur in deformed tracts, extreme care is required to distinguish between structures of sedimentary and tectonic origin, and in reconstructing direction of current movement.

7. TRACING TURBIDITY CURRENT DEPOSITS DOWN THE SLOPE OF AN ALPINE BASIN

ALBERT CAROZZI
University of Illinois, Urbana, Illinois

Black pelagic limestones were deposited in the sedimentation basin of the Nappe de Morcles (High Calcareous Alps) during the Upper Jurassic. This deep-water sequence which generally reaches 100–150 meters in thickness, was interrurted at least nine times by coarse-grained clastic beds laid down by turbidity currents. The main constituents of these clastic beds are broken or intact reef-organisms, oolites, and clastic minerals, displaying well characterized graded-bedding. This foreign material originates in the northern margin of the basin along which fringing reefs were growing. As these clastic beds are traced out to sea, as indicated by the regional paleogeography, they disappear one by one; moreover, peculiar topographic conditions allow the study of the textural modifications of a given bed at least 40 kilometers down the basin slope, along the inferred main direction of flow of the turbidity currents. Particularly interesting is the behavior of the apparent maximum diameter of a

given clastic component (index of clasticity) measured at the bottom of the bed, as it may reveal the horizontal grading along the direction of flow. Two main types of variation have been recognized:

1. *Normal types*, corresponding to beds laid down by individual turbidity currents.
   a. The clasticity starts with high values and decreases down the slope following a regular curve toward the end of the bed.
   b. The clasticity decreases along a straight line.
   c. The clasticity remains constant along the entire length of the bed.
2. *Composite types*, corresponding to beds laid down by the interference action of two or more turbidity currents. The clasticity curve corresponds to the juxtaposition of any one of the normal types. Interference of two turbidity currents was commonly observed, the second flow starting deposition when the first was near its end. The clasticity curve displays a first gradual decrease succeeded by a rapid increase (due to mixing) leading to a second and similar diminution down the slope.

These variations of clasticity along the inferred direction of flow of turbidity currents are in general agreement with the experimental data as well as with the mechanics admitted for this peculiar type of sedimentation. However, further studies are required to ascertain their possible use in correlation.

PRESIDENTIAL ADDRESS

Tuesday, April 24, 8:45 A.M.

Grand Ballroom, Hilton Hotel

JOINT SESSION

IN DEFENSE OF OUTDOOR GEOLOGY

FRANCIS J. PETTIJOHN

(For complete address, please refer to A.A.P.G. *Bulletin*, Vol. 40, No. 7.)

Tuesday, April 24, 1:45 P.M.

Waldorf Ballroom, Hilton Hotel

GENERAL PALEONTOLOGY AND STRATIGRAPHY

Presiding: CHARLES COLLINSON, Illinois State Geological Survey, Urbana, Illinois, AND STUART A. LEVINSON, Humble Oil & Refining Company, Houston, Texas

1. ECOLOGICAL INTERPRETATIONS OF THE PLIOCENE AND PLEISTOCENE STRATIGRAPHY IN THE GREAT GREAT PLAINS REGION

JOHN C. FRYE* AND A. BYRON LEONARD

Illinois State Geological Survey, Urbana, Illinois; and University of Kansas, Lawrence, Kansas

In the Great Plains Region a record of changing physical environment, exemplified by fossiliferous sediments, is well preserved. Although broken by unconformities, the record is exceptionally complete from late Miocene or early Pliocene time to the present. Interpretations are based on studies extending from west-central Texas to western Nebraska. Stratigraphic classification and correlations are included as a basis for discussion of changing environmental conditions. Of prime utility in reconstruction of past ecologies are the almost complete succession of fossil molluscan faunas, the abundant plant remains of the Pliocene, the well preserved and extensive Pleistocene buried soils, and the striking development of secondary calcium carbonate as well as the character and distribution of the clastic sediments.

In earliest Pliocene there existed a subdued erosional topography, moderately well watered and vegetated. Alluviation, initiated along major valleys, spread laterally, overlapping gentle erosional slopes, and gradually reduced the local relief. Through the Pliocene there was a slow but progressive drying of the Plains, with gradual elimination of branchiate snails, modification of the typically prairie flora, decline of regional water table and extensive development of caliche. During late Pliocene the marked fineing of sediments suggests a decrease in volume of water

* Person presenting paper.

flowing through the region. Finally, alluviation ceased and an alluvial plain of little local relief, with a climate perhaps as dry as the present, persisted at essential equilibrium for a significant period. With the climatic reversal in earliest Pleistocene, branchiate snails again appeared, and major streams incised valleys—partly alluviated in Nebraskan time. By Kansan time the Plains, after a period of major incision, were again a mesophytic prairie well populated with branchiate snails. The subsequent history of the Plains is characterized by fluctuating but progressive desiccation, evidenced by the complete disappearance of branchiate snails; prevalence of Chernozem, Chestnut, Reddish Chestnut, and Brown soils in interglacial positions; striking increase of loess deposits; and progressive increase in topographic relief. In the Bradyan interval conditions of semi-aridity, similar to those existing today, mark the final phase in progressive desiccation.

2. PROBLEM OF SCIENTIFIC NOMENCLATURE APPLICABLE TO FRAGMENTARY FOSSILS

RAYMOND C. MOORE AND P. C. SYLVESTER-BRADLEY*
University of Kansas, Lawrence, Kansas;
University of Sheffield, Sheffield, England

Among fossil remains of animals are multitudinous dissociated fragments which cannot reliably be identified as parts of any known species or genus of whole animals. These include isolated skeletal elements of coccoliths, sponges, octocorals, holothurians, crinoids, cystoids, echinoids, asterozoans, annelids (scolecodonts), the minute toothlike bodies of unknown zoological affinities called conodonts, and such objects as opercula of gastropods, aptychi of ammonoids, fish scales and fin spines, and otoliths. A majority of these fragmentary fossils can be classified readily on form characters and are found to have much importance in stratigraphic paleontology. A retarding influence in describing and illustrating fossil fragments, however, is the great difficulty which has been encountered in devising a suitable system of nomenclature for them. Confusion arises from naming fragments in the manner of whole-animal taxa or treatment of them as "form-genera" and "form-species" subject to zoological rules, and only chaos can result from acceptance of the Paris (1948) decision that names for such fragments are "technical terms" belonging outside the scope of zoological nomenclature. Solution of the problem is offered in proposing for fragmental remains of animals a distinct category of classificatory units termed parataxa (associate taxa) which are subject to all zoological rules like taxa. Such names applied to paragenera, paraspecies, etc., would not be transferable to correlative taxa used for whole animals. Procedure for establishing nomenclature of parataxa is outlined.

* Person presenting paper.

3. SIGNIFICANCE OF LIVING FORAMINIFERAL POPULATIONS ALONG THE CENTRAL TEXAS COAST

FRED B. PHLEGER
Scripps Institution of Oceanography,
La Jolla, California

Living foraminiferal populations have been studied from San Antonio, Mesquite, and Aransas Bays and from numerous open-ocean samples across the adjacent continental shelf. This work is a part of A.P.I. Project 51.

Living populations in the bays average 50–200/10 ml. wet sediment at most stations. They are considerably higher in upper San Antonio Bay than elsewhere and are largest off the delta of the Guadalupe River. The total populations (dead and living) are unusually high, most stations having more than 10,000/10 ml. wet sediment. Low living populations at some stations appear to be related to conditions of deposition. The living population shows the same biofacies pattern as the total population.

Living populations on the continental shelf are approximately the same size as in the bays. Marked faunal boundaries occur at 10–20 m. and 40–60 m. Less distinct boundaries occur at a variety of other depths. Living and dead distributions are similar except that dead specimens tend to be more widespread downslope than living ones. Shallow depth ranges are more reliable than deep ones.

Relative rates of deposition are suggested by ratios between live and total populations. These data suggest that sedimentation is relatively fast near the Guadalupe River and is very slow in the lower bays. Rates are intermediate on much of the shelf and very low on the outer shelf. High populations of Foraminifera seem to indicate a slow rate of terrigenous deposition.

4. PALEOECOLOGY OF THE FLORIDA MIOCENE*

HARBANS S. PURI† AND ROBERT O. VERNON
Florida Geological Survey, Tallahassee,
Florida

The type section for the Miocene in southeastern United States is in West Florida, where these rocks are divided into three Stages: Tampa, Alum Bluff, and Choctawhatchee.

The Tampa Stage is divided into two lithofacies: the calcareous St. Marks facies and the silty Chattahoochee facies. The Chattahoochee facies was deposited in moderately shallow warm water in a pro-deltaic environment where clastic sedimentation was going on. Downdip the calcareous St. Marks facies was deposited in deeper water where more calcium was available.

The Alum Bluff Stage is subdivided into four lithofacies: Oak Grove, Shoal River, Hawthorn, and Chipola. The Oak Grove facies was deposited

* Publication authorized by the Director, Florida Geological Survey.

† Person presenting paper.

in a localized shallow marine-to-brackish water transgressive-regressive phase of the Alum Bluff sea. The Oak Grove sediments are mostly sandy and sparsely fossiliferous and have yielded a microfauna which is similar to that common in the modern brackish-water bays. Downdip the Shoal River sediments are predominantly sandy with some intervening shell marl beds. The dominant fauna of these sediments is typically brackish as shown by the predominance of *Streblus beccarii, Elphidium gunteri, Anonocytheridae* sp., *Haplocytheridea bassleri* and *Perisso-cytheridea matsoni*, among other brackish water species. A slight influx of inner neritic forms is also present in the Shoal River. These inner neritic forms, though not living in modern bays, are represented by the empty tests and carapaces which are washed into the bays from the open sea at high tides.

The transgressive Alum Bluff sea moving over the sediments of the Tampa Stage deposited Chipola sediments. Both the organic tests and precipitation of calcium carbonate contributed to the calcareous nature of the Chipola facies. The Chipola microfauna is indicative of warm water (20–30°C.) conditions, and the bulk of the Chipola facies was deposited in a depth range of 110 meters.

The Hawthorn facies in West Florida consists of a continental subfacies that occurs around the Alum Bluff area. The sediments in this continental facies are composed of coarse-to-fine sand and some silt, with abundant impressions of fossil leaves. In the area west of the Alum Bluff and around Tallahassee, the Hawthorn facies is represented by the deltaic subfacies. This deltaic subfacies consists of variegated, massive-to-crossbedded sands, pebble conglomerate, and fuller's earth deposits. These deltaic sediments, whenever fosiliferous, yield a meager fauna of *Streblus beccarii* var. and species of *Elphidium*. This subfacies fans out into northern and western Florida from a point at the Georgia-Florida line north of Tallahassee. The marine subfacies outcrops in Columbia County and Alachua County, and occurs in subsurface in South Florida, where most of the section is shallow marine and consists of several shell beds with abundant oyster and *Pecten* shells deposited in a near-shore calcareous environment. This subfacies is stratigraphically lower than the phosphate subfacies that crops out in Alachua County and in the phosphate district. In northern Florida, the Hawthorn facies is overlain by beds of Choctawhatchee age, which have formerly been called Nassau marl. In West Florida, except in the Tallahassee Hills, the Hawthorn is overlain by sediments of Choctawhatchee. In the Central Highlands, the Hawthorn laps on beds of Ocala age. Throughout the rest of the State, the Hawthorn is overlain by the Choctawhatchee sediments.

The Alachua facies is the terrestrial equivalent of the Hawthorn in central and northern Florida, where these beds carry a middle and upper Miocene vertebrate fauna, silicified wood and basal rubble of phosphate rock. These sediments occur in solution pits, sinks and valleys along northwest-southeast trends that parallel the Ocala uplift.

The Choctawhatchee Stage is subdivided into four biofacies in West Florida: *Yoldia, Arca, Ecphora* and *Cancellaria*. The *Yoldia* facies represents the westernmost shallow-water marine sediments of the Choctawhatchee, deposited locally in the vicinity of the type locality. The microfauna is indicative of shallow (10–110 meters) water inner neritic conditions. Downdip, the *Arca* facies microfossil assemblage is indicative of depth zone between 30 and 100 meters. The bulk of *Ecphora* and *Cancellaria* facies, which is transgressive-regressive in nature, seems to have been deposited between 128 and 200 meters. The upper portion of the *Cancellaria* facies, which overlies the *Ecphora* facies in places, was deposited under more shallow conditions.

Tamiami facies in South Florida is a lithologic and faunal equivalent of the *Ecphora-Cancellaria* facies of West Florida. Downdip, in the South Florida Embayment area, Tamiami intergrades into the *Arca* facies. The *Arca* facies of the South Florida Embayment area was deposited under similar conditions as its counterpart in West Florida.

5. SEDIMENTARY REFLECTIONS OF THE DEPOSITIONAL ENVIRONMENT IN A COASTAL LAGOON

HARRIS B. STEWART, JR.

Scripps Institution of Oceanography, La Jolla, California

Samples of the bottom sediments and overlying water from San Miguel Lagoon in Baja California, Mexico, show that striking horizontal and vertical sediment variations are reflections of comparable areal and temporal variations in the environment. Particle-size distributions interpreted in terms of depositional processes reveal the lagoonward extent of ocean-derived sediments deposited by tital action, washovers, and wind action. River-derived material extends well seaward of the lower limit of the river environment in the water at the time of sampling, probably reflecting flood deposition. Living plants and animals are abundant, but a maximum of only 1 percent organic material was found in black muds rich in H_2S. Lowest oxygen values occur in the water overlying these black muds, probably related to the high rate of organic decomposition. Diurnal variation graphs of dissolved oxygen and pH are compared with values obtained from water samples taken at differnet times of the day and used to delineate 5 aqueous environments within the lagoon. These environments correlate with the underlying sediments in the areas where deposition was taking place at the time the water was sampled. The water samples were obtained while the bay barrier isolated the lagoon from the ocean and no tidal currents operated in the lagooon. The river at that time was not in flood. Hence the sediments deposited primarily by tidal action and those deposited by floods do not reflect the water overlying them at the time of sampling.

Criteria are discussed for recognition of ancient lagoon deposits in the geologic record.

6. RECENT AND ANCIENT PENETRANTS

MAXIM K. ELIAS
University of Nebraska, Lincoln, Nebraska

Some microscopic plants and invertebrates settle upon the surface and bore into the walls of various larger organisms, or some of these let the growing walls engulf them. Their presence is revealed in the course of detailed morphologic and anatomic study of the skeletons of living and fossil invertebrates. Besides the better-known clinoid sponges and the boring algae, minute ctenostomatous bryozoans penetrate not only molluscan, but also some benthonic foraminiferal tests of Tertiary to Recent age. Equally small plants, probably fungi, penetrate the tests of some pelagic foraminifers, whereas other enigmatic plants are attached to and penetrate the walls of some ramose cyclostomatous and trepostomatous bryozoans ranging in age from Ordovician to Recent. Some puzzling structures in and upon the walls of brachiopods, bryozoans and corals may be the result of activity by some penetrants.

7. MARINE ECOLOGY AS AN AID IN THE TEACHING OF INVERTEBRATE PALEONTOLOGY AND STRATIGRAPHY

WILLIAM H. MATTHEWS III
Lamar State College of Technology,
Beaumont, Texas

Academic institutions located near the coast have at hand an excellent outdoor laboratory for students of invertebrate palontology and stratigraphy.

A study of various marine habitats enables the student to observe (1) a variety of ecological situations, (2) the organisms inhabiting them, (3) adaptations of these organisms to different environments, and (4) their effect on sedimentary environments.

On Galveston Island, Texas, the following habitats may be conveniently studied:

1. *Rocky shore.*—At Galveston this is a man-made environment resulting from the construction of a pair of stone jetties. Wave action, scour and salinity variations are important factors in this environment.
2. *Sandy beach.*—The beaches support relatively few organisms, but burrowing pelecypods and gastropods are found along the strand. Many dead shells of animals inhabiting the sands extending from the shore may also be collected on the beaches. These specimens are useful for comparative material in paleontology.
3. *Mud flat and brackish water.*—Forms typical of this habitat may be studied with respect of environment adaptation.
4. *Near-shore bottom.*—Many neritopelagic and nektoplanktonic forms may be collected by means of a small dredge.

The above habitats support interesting faunas representing different sedimentary and biological environments. A comparison of these faunas reveals many examples of faunal zonation, environmental adaptation and evolutionary diversification. Studies of this type introduce the student to the paleoecological approach in the solution of paleontological and stratigraphic problems.

The marine field trip should be followed by a geological field trip and an effort made to correlate the results of the two studies. Written reports are required for both the ecological and geological trips.

Wednesday, April 25, 9:00 A.M.

Waldorf Ballroom, Hilton Hotel

SYMPOSIUM: PALEOECOLOGY

Presiding: H. S. LADD, U. S. Geological Survey, Washington, D. C., AND BERNHARD KUMMEL, Harvard University, Cambridge, Massachusetts

1. INTRODUCTORY REMARKS

ROBERT R. SHROCK
Massachusetts Institute of Technology,
Cambridge, Massachusetts

2. PLAN OF SYMPOSIUM

HARRY S. LADD

3. MARINE LEVEL-BOTTOM ANIMAL COMMUNITIES OF RECENT SEAS

GUNNAR THORSON
Copenhagen Zoological Museum,
Copenhagen, Denmark

Out of the 850,000 species of Recent animals, 140,000 (16%) only are marine. Some of these

are planktonic, the majority is associated with rocks and vegetation, and the rest with sandy and muddy bottoms. This means that the level-bottom areas of the sea, though covering more than half the surface of our globe, are inhabited by only 2–3 percent of all Recent species of animals. Quantitative samples from several seas prove that the same types of level-bottom substrata at similar depths are dominated by invertebrates belonging to the same genera but to different species, thus forming chains of "parallel communities" in all seas, arctic and tropical, and being adapted to the temperatures of the latitudes in which they live. The metamorphosing pelagic larvae are able to respond positively or negatively to a bottom substratum. and this substratum seems to be the main factor responsible for their settling and, accordingly, for the qualitative composition of each level-bottom community. In the open sea a muddy bottom will normally be an indicator of calm water, i.e. greater depth, stable temperature and salinity, whereas a bottom covered with coarse sand means turbulent water at shallower depth, i.e. larger fluctuations in temperature and salinity. The substratum, directly responsible for the composition of the animal community, thus at the same time tells us a good deal about the local ecological conditions. Recent level bottoms are dominated by astonishingly few genera and species, which one day will be the geological guide fossils for our period.

4. CONDITIONS OF LIFE IN THE SEA

JOEL W. HEDGPETH

Scripps Institution of Oceanography,
La Jolla, California

Although the volume of the sea is several hundred times that of the terrestial environment (including lakes), most of the consideration of ecological factors and ecological theory have been built around our knowledge of the terrestrial environment, which lacks the three dimensional, fluid nature of the marine environment. It has been said that sea water is an "organic puree," and one of the most pronounced differences between the life of the sea and that of other environments is the abundance of organisms in the sea that are adapted to feed upon finely suspended and colloidal material. Another major difference between sea and land in particular is the manner in which the products of organic activity (such as vitamins and antibiotic substances) are suspected to affect other populations in the sea on a large scale, again a reflection of the ambient, three dimensional medium that is the sea. Whether life in the sea proceeds at a more or less efficient pace than on land is at present an open question, but it does appear that most food chains in the sea are longer and more involved than on land, an indication, perhaps, that the greater space provided by the sea in turn provides more niches, as well as a greater dispersal of materials through the environment. It is inadvisable to apply the major concepts of terrestrial ecology to the sea without careful thought, since such concepts as succession and climax have been built around the interaction of climate and biota, with climate playing the controlling role, whereas the character of the marine climate (understood as prevailing conditions) is as yet inadequately understood. A case in point is the argument whether certain bottom organisms actively select a type of sediment because of some organic substance in it or whether both organisms and sediment type are where they are because of common hydrographic conditions.

5. PALEOECOLOGICAL EVIDENCE FURNISHED BY FOSSILS

HARRY S. LADD
U. S. Geological Survey

The shape of a fossil or the structure of its shell—external or internal—may give a clue to the mode of locomotion of nektonic or benthonic types and may suggest the general habitat of either sedentary or pelagic forms. In some instances the position of a shell in the rock or the perfection of its preservation may indicate or even demonstrate that it was buried where it lived. Many of the most highly populated marine areas, however, are not sites of deposition and it is evident that many fossil shells were transported prior to final burial. This may be shown clearly by incomplete or worn fossils, in assemblages containing both marine and brackish or fresh water types or in assemblages containing fossils of widely different ages. Fossil faunas in which elongate shells are uniformly oriented or in which there appears to have been selective sorting may be indicative of wave or current action. Preservation of color or traces of a color pattern may suggest the depth at which the animal lived and, perhaps, the orientation of its shell in life. Chemical studies of the composition of shells that appear not to have been altered by the passage of time may reveal much about the temperature or other features of the original environment. Concentrations of fossils on a single bedding plane may suggest catastrophic death due to one of several causes.

All paleoecological interpretations based on fossils must, however, be made with caution, particularly those involving extinct groups or forms that have no close living relatives.

6. PALEOECOLOGICAL EVIDENCE FROM SEDIMENTS

BERNHARD KUMMEL

Harvard University, Cambridge, Massachusetts

Much information about the environments of fossil organisms may be obtained from the rocks that contain the fossils. Texture may reveal a good deal about the type of bottom, the clearness or turbidity of the water, possibly even the depth of deposition; certain fabrics seem to characterize specialized sedimentary environments. The occurrence of graded bedding may be most revealing, particularly if it can be related to changes in faunal content. Certain types of black shale are formed in areas where there is a dearth of oxygen

and organic matter is accumulated faster than it can be oxidized.

Sedimentary structures such as ripple marks that persist laterally or vertically may be used to support broad generalizations involving oceanic circulation. Other markings, such as cross-bedding, are indicative of shallow depths or other specialized conditions.

The occurrence of a high content of calcium carbonate, including oolites or concentrations of glauconite, phosphorite or nodular manganese may also be used in interpreting past environments.

7. DIATOMS AS PALEOECOLOGICAL INDICATORS

KENNETH E. LOHMAN

U. S. Geological Survey, Washington, D. C.

Diatoms, by virtue of the minute size and durability of their siliceous shells, are widespread over the globe, and occur in many types of sediments deposited in marine, brackish, or freshwater basins. Many species prefer rather restricted temperature ranges, from pools in ice floes at one extreme to hot springs at the other. They are readily trasported in reproductive condition over long distances by ocean currents, wind, birds, and other agencies, with the result that at any one period of geologic time a group of species adjusted to a particular environment can be found anywhere in the world where that environment exists. Furthermore, any assemblage of fossil diatoms found, particularly in Tertiary rocks, contains a mixture of extinct species and those still represented in living assemblages.

This fortunate combination of properties renders the diatoms exceptionally useful for paleoecological interpretations, as well as for stratigraphic correlations.

Marine diatoms are now known from rocks of late Mesozoic to Recent age; non-marine diatoms from rocks of Oligocene to Recent age. The completeness of the earliest known assemblages, and their degree of diversification, however, strongly suggest that diatoms, both marine and non-marine, must have lived in still earlier geologic periods.

The criteria used in the taxonomic classification of these organisms, both living and fossil, are based upon the shape and intricate structure of the siliceous shell, and not on the ephemeral soft parts. This is particularly advantageous for paleoecological interpretations as it reduces the possibility of confusion between the biologist working with the living diatoms and the paleontologist using the fossil ones. It thus has the effect of welding the literature on Recent diatoms with that of the fossils into one harmonious continuum of data equally intelligble to biologists and paleontologists.

8. NEW TECHNIQUES IN PALEOECOLOGY

PHILIP H. ABELSON

Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C.

Physical and chemical studies of fossils are revealing new types of information concerning paleoecology and paleobiochemistry. Measurements of O^{16}/O^{18} ratios in calcareous fossils by Urey, Lowenstam, Epstein, and McKinney yielded paleotemperatures and have permitted examination of life cycles of some organisms.

Organic constituents have been found in many fossils. Amino acids, including alanine, glutamic acid, glycine, isoleucine, proline, and valine, have been found in a specimen of the armored fish, *Dinichthys terrali*, from the Devonian Ohio black shale. Laboratory studies indicate that many other chemicals of biological origin have sufficient stability to endure for equally long periods of time.

This talk will review briefly the present status of these new developments and point out further opportunities for study.

Wednesday, April 25, 1:45 P.M.

Waldorf Ballroom, Hilton Hotel

MINERALOGY AND SEDIMENTARY PETROLOGY

Presiding: LEWIS CLINE, University of Wisconsin, Madison, Wisconsin, AND ELY MENCHER, Massachusetts Institute of Technology, Cambridge, Massachusetts

1. UNIFORMITARIANISM IS A DANGEROUS DOCTRINE

PAUL D. KRYNINE

The Pennsylvania State University, University Park, Pennsylvania

Geologic extrapolation into the past is vitiated by:

1. *Immediate causes*
   a. Post-glacial phenomena are geologically abnormal, as they form less than 2 percent of Post-Cambrian history—excessive periglacial and desertic eolian activity, aridity, etc.
   b. Common mistake of misinterpreting *fossil* glacial and *pluvial* phenomena as being recent (pluvial red soil or alluvial fans in young post-glacial deserts, etc.)
2. *Intermediate causes.* Large-scale emergence of continents, excessive since Permian and particularly Pleistocene. Results are:
   a. Considerable decrease of *shallow* epicontinental seas and related large-scale, inorganic limestone-dolomite and orthoquartzite deposition; converse increase in size of deltas, with drastic textural changes in detrital sediments.
   b. Changes in basic morphology and sedimentary performance of geosynclinal

basins from Paleozoic into Tertiary. Older geosynclines generally restricted between rigid crystalline shield segments (so called "kratonic" pieces) or, although located on subsiding plastic (so called "mobile") continental borders, nevertheless almost landlocked (sedimentationally "closed") by smaller land-masses (e.g. Appalachian trough) and furthermore *connected* with shield-covering (so called "kratonic") epicontinental seas. Tertiary and recent basins occur mostly on extreme borders of continents, abutting against oceanic abysses (sedimentationally "open"). This has changed all principal textural and compositional modes of both carbonates and graywackes.

3. *Ultimate causes.* Increase in rate (tempo) and change in morphology of tectonic deformation since early Paleozoic toward a more intermittently frequent distribution and a basic upward tendency. Results, besides physiographic emergence of continents, are increase in abundance of actively eroded crystalline massifs (as against slate-phyllite source areas) and predominance of erosion over chemical weathering—mean feldspar content of Paleozoic sandstone less than 5 percent; of Mesozoic-Tertiary more than 20 percent with accompanying kaolinite increase; conversely mean phyllite-slate fragment content of Paleozoic sandstones more than 20 percent as against 10 per cent in Tertiary, with corresponding decrease in illite. A similar change occurs also in the heavy accessory suite. These changes are qualitative and abrupt, i.e. result from different provenance, rather than quantitative and gradual (i.e. due to gradual intrastratal alteration). No age alteration will transform a piece of granite inside a sediment; nor will the kaolinitic matrix of a sediment be transformed through age into a piece of large, sand size, perfectly recognizable fragments of illite-slate, complete with internal structure and clear-cut boundaries. Conventional uniformitariansim or "gradualism," i.e. the doctrine of unchanging change is verily contradicted by all post-Cambrian sedimentary data and the geotectonic histories of which these sediments are the record. Thus quantitative interpretations of the Ordovician from the Recent are meaningless.

2. TERTIARY REEF LIMESTONES FROM SOUTHERN LOUISIANA AND GUAM

McLain J. Forman* and Seymour O. Schlanger

c/o Gordon Atwater, Consulting Geologist, New Orleans, Louisiana; U. S. Geological Survey, Washington, D. C.

Striking similarities in fossil content and lithology in reef limestones from southern Louisiana and Guam indiate that biologically similar reefs existed in these two areas during Tertiary time. The reefs in southern Louisiana are largely restricted to *Heterostegina* zone strata of Oligocene. age; the Guam reefs are of lower Miocene age.

Topographic highs formed by intrusion of piercement-type salt domes afforded favorable conditions for local reef growth in portions of southern Louisiana, whereas a more extensive reef developed on a shallow-water shelf area in extreme southeastern Louisiana. An older volcanic ridge and the flanks of an intermittently active submarine volcano were the sites of reef growth at Guam.

Rock types common to both areas are: (1) poorly sorted conglomerates consisting dominantly of algal and coral fragments, tests of foraminifera, and mollusk shells, all cemented by encrusting algae and foraminifera; (2) well-sortedc onglomerates and calcarenites made up of tests of foraminifera and fragments of articulate and encrusting algae in a fine-to-medium grained matrix; and (3) foraminiferal calcarenites containing large benthonic types and small pelagic types in a fine-grained matrix.

These three rock types are interpreted respectively as indicating deposition in: (1) shallow-water, reef and near-reef environments; (2) fore-reef or back-reef areas, below depths at which coral and encrusting algae flourish; and (3) deeper waters beyond the zone of reef-detritus deposition in areas where pelagic foraminifera contributed significantly to bottom deposits.

These similarities in rock types and facies associations illustrate the tendency of reefs to develop in characteristic patterns on submarine topographic highs, regardless of the original substrate.

3. THE MINERALOGY OF THE FUNAFUTI DRILL CORES AND ITS BEARING ON THE PHYSICOCHEMISTRY OF DOLOMITE

Robert F. Schmalz

Belmont, Massachusetts

The mineralogy of cores from Funafuti atoll was of considerable importance in the formulation of theories of dolomitization. The original analyses were made by methods which today appear unreliable however, and the present study re-examined the cores by x-ray diffraction techniques.

The distribution of carbonate mineral species was confirmed, in general, by the present study. (1) Aragonite, common near the surface, diminishes in abundance with depth and vanishes below 220 feet. (2) Dolomite, entirely absent in the upper portion of the core, is dominant and universally present below 640 feet. (3) Calcite, the dominant mineral at depths less than 640 feet, appears only in thin horizons below the point where dolomite is first found. (4) The magnesium-rich horizon near the top of the core is due not to the presence of dolomite, but to magnesium in metastable solid solution in calcite.

The systematic distribution of mineral phases revealed by the present study admits of physico-

* Person presenting paper.

chemical interpretation. It is proposed that porous limestones of the atoll are in chemical equilibrium with sea-water at all depths. The chemical system, limestone plus sea-water, lies in the stability field of calcite plus magnesium-ion above 640 feet; below this level, probably due to increased hydrostatic pressure, dolomite is the stable phase.

Unstable organically precipitated phases, aragonite and high-magnesium calcite, persist in depth beneath the zone of organic activity due to their slow rate of reaction to the stable phase.

Tentative sub-solidus phase diagrams conforming to these data are discussed.

4. HEAVY-MINERAL ASSEMBLAGES OF THE CORAL-REEF LIMESTONES AT THE BASE OF THE TRICHINOPOLY CRETACEOUS (CENOMANIAN TO DANIAN), SOUTH INDIA

C. Gundu Rao

The Pennsylvania State University, University Park, Pennsylvania

Thirty samples representing the southern and northern facies of the coral-reef limestones at the base of the Trichinopoly Cretaceous (S. India), and eight samples of the Cullygoody limestones occurring along the southeastern border of this area were subjected to heavy mineral analysis and the following minerals recognized: magnetite and ilmenite, tourmaline, hornblende, epidote, staurolite, kyanite, garnet (colorless and pink), zircon, rutile, enstatite, hypersthene and apatite. Magnetite and ilmenite, and garnet (colorless and pink) form the main assemblage.

Although the heavy minerals in the different exposures of the coral-reef limestones are generally similar, the Naicolum ridge and the basal part of the Terany ridge of the Southern facies, show a poor concentration of garnets. The heavy mineral assemblage of the coral-reef limestones differs from that of the underlying upper Gondwana plant-bearing beds in being poor in zircon and rutile, and practically devoid of tourmaline. The heavy mineral assemblage of the Cullygoody limestone differs from that of the coral-reef limestones in being rich in zircon and rutile. It resembles that of the upper Gondwana rocks of this region in being rich in zircon and rutile but differs from the same in being poor in epidote and practically devoid of tourmaline.

Statistical studies in the zircons of the (1) coral-reef limestones and the (2) Cullygoody limestone has shown that both of these limestones include zircons of two generations. The first generation zircons in the coral-reef limestones may be explained as directly derived from the original source rocks, whereas the second generation ones seem to have been reworked from the underlynig upper Gondwanas. But in the case of the Cullygoody limestone the occurrence of second generation zircons is difficult to explain in view of the absence of any known upper Gondwana rocks or any other sedimentary formation underlying this limestone.

The latter part of the paper presents the results of some statistical investigations on the lines of Smithson in his studies on the Triassic and Jurassic rocks of Yorkshire.

The ultimate source of the detritus in these limestones seems to have been in the charnockites, granites and gneisses lying to the west and south of the area.

5. PETROGRAPHY AND GENESIS OF THE OGALLALA "ALGAL LIMESTONE" IN KANSAS AND ADJACENT STATES

Ada Swineford,* John C. Frye, and A. Byron Leonard

State Geological Survey of Kansas, Lawrence, Kansas; Illinois State Geological Survey, Urbana, Illinois; University of Kansas, Lawrence, Kansas

Petrographic study of 34 oriented samples of "Algal limestone" from the upper part of the late Tertiary Ogallala formation in Kansas, Oklahoma, and west Texas indicates that the rock sampled was developed predominantly by soil-forming processes acting upon sands and silts of the uppermost Ogallala. The absence of fossils (especially diatoms, which invariably occur in all other limestones examined from many levels in the Ogallala), replacement of sand grains by calcite, anomalous distribution of detrital grains with respect to oolites and bulbous structures, and the inverted orientation of the bulbous structures themselves, all argue against algal origin of the rock. Presence of as much as 2 percent barite in veins cutting across concentric laminae suggests increase of sulfate ion during periods of excessive aridity.

The origin of the limestone is similar to that of the old caliche in southeastern New Mexico described by Bretz and Horberg, except that limestone gravels were not required for its formation. The concretionary structures are analogous to those formed in bauxites in the zone of concretion. Conditions favoring development of "Algal limestone" were (1) presence of rocks with easily soluble minerals yielding residues rich in Ca^{++} ion; (2) effective rock permeability; (3) deficient rainfall and long dry periods; (4) low topographic relief; and (5) time.

6. SHELFEDGE, CALCAREOUS PROMINENCES IN THE NORTHEASTERN GULF OF MEXICO

John C. Ludwick† and William R. Walton

Gulf Research & Development Company, Houston, Texas

A survey of the topography, sediments, and faunas in the northeastern Gulf of Mexico has demonstrated the presence of a belt of calcareous, reef-like features near the edge of the continental

* Person presenting paper.
† Person presenting paper.

shelf between 40 and 55 fathoms. The zone of prominences is approximately one mile wide, discontinuous with 10–20 mile gaps, and has an average relief of 30 feet.

A detailed study has been made of a five-square-mile section of this feature at the edge of the shelf south of Mobile, Alabama. The sedimentary and faunal characteristics of the deposits form natural groupings that can be correlated with submarine topography, past and present ecological conditions, and history of the region.

This reef is intermediate in stage between active growth and fossilization and possesses some characteristics of both stages. Past and present processes and environments, both subaqueous and subaerial, have tended to distribute and modify the sediments and faunas so as to present a complex pattern of indigenous, relict and reworked sedimentological characteristics in the area today.

The reef flourished under previous environmental conditions of shallower, possibly warmer, waters. It has not survived a rise in sea level and is now undergoing slow modification by aftergrowth and self-burial. The probability is high that this feature will be preserved in the geologic column. In some characteristics, it resembles known ancient reefs.

7. SILURIAN REEFS OF THE NORTHERN EDGE OF THE EASTERN INTERIOR BASIN

JOHN B. SANGREE, JR.

Northwestern University, Evanston, Illinois

A study of the reefs in the Silurian outcrop region of northern Indiana and northeastern Illinois indicates a rough morphological classification of the reefs into: (1) broad, horizontally bedded reefs, (2) intermediate reefs with large flat tops and steeply dipping marginal talus beds, and (3) isolated reefs composed of a high narrow central core surrounded by talus beds. These reef types are gradational and numerous subdivisions are possible. Characteristic lithologies are associated with each type. Type 1 is distinguished by a varied, robust fauna, commonly associated with oolitic beds. The horizontally bedded rocks found on the flat tops of reef type 2 are very similar to the lithology of type 1. The steeply dipping reef-derived flank beds vary from conglomeratic to sand-sized coquinas. Reef type 3 consists of coarse, obscurely bedded fossil-fragmental core rocks, combined with flank rocks which vary widely in texture and fauna, depending on growth conditions. The major factors controlling reef differentiation in this region are depth, turbidity, salinity, and nutrient supply of the sea, and topography and tectonic stability of the substrate. Characteristic associations occur between reef and inter-reef beds, indicating some modification of the off-reef environment by the reef proper. The complexity of these associations are largely responsible for the difficulties of correlation encountered in areas of reef growth. A better understanding of environmental associations should lead to more satisfactory correlations.

8. TRANSITIONAL PERMO-PENNSYLVANIAN SEDIMENTS OF THE ROWE-MORA BASIN, NEW MEXICO

RAYMOND SIDWELL AND G. FREDERICK WARN*

Texas Technological College, Lubbock, Texas

These sediments vary in thickness from approximately 50 feet in the southern part of the basin to 3000 feet in the northwest portion. They were deposited in a post-geosynclinal environment, beginning on an unstable shelf in late Pennsylvanian. Shelf deposits were transitional from marine to continental, becoming dominantly continental in the Permian and eventually returning to marginal marine in late Permian (Yeso and San Andres). Surrounding highlands influencing sedimentation included the Front Range. Uncompahgre-San Luis Uplift, Pederenal Range and Sierra Grande-Las Animas Arch. Control was exerted locally by basement-complex islands. The positive areas were uplifted in late Pennsylvanian and early Permian and were progessively lowered by erosion during middle and late Permian time. Clastic rock types and their heavy-mineral content suggest source areas that were predominantly igneous (granitic) but which included mildly metamorphic rocks.

The Transition Beds consist mainly of a red-bed sequence. The Pennsylvanian portion of the Transition Beds includes thin, impure limestones and marls; minor amounts of arkosic limestone; micaceous, sandy shales and clays; and arkosic, calcareous sandstones and conglomerates. These pass laterally and/or upward into probable Wolfcampian deposits of limy, arkosic coarse sandstones and conglomerates characterized by wedging and cross-bedding. Massive conglomerates with rounded quartz pebbles and subangular quartzite pebbles and cobbles occur above the arkosic section. These are followed by variable arkoses and micaceous, calcareous clays and sandy silts and shales. Marls tend to be conspicuous in most of the section. Sandstones in the lower and upper thirds of the section are notably calcareous.

Heavy minerals in $\frac{1}{2}$ to $\frac{1}{16}$ mm. grain sizes appear in the following order of abundance in the lower Transition Beds: magnetite, mica, tourmaline, garnet, zircon, hornblende and rutile. The order of abundance in the upper Transition sequence is: magnetite, garnet, mica, tourmaline, zircon and rutile.

* Person presenting paper.

Thursday, April 26, 9:00 A.M.
Waldorf Ballroom, Hilton Hotel

MINERALOGY AND SEDIMENTARY PETROLOGY

Presiding: HAROLD N. FISK, Humble Oil and Refining Company, Houston, Texas, AND HAYDN H. MURRAY, Indiana University, Bloomington, Indiana

1. ALICE IN GRAYWACKELAND

PAUL D. KRYNINE
The Pennsyvlania State University, University Park, Pennsylvania

A recent eruption of "graywacke" papers (Bockman; Dapples, Krumbein and Sloss; Folk; Gilbert et al.; Kuenen; Packham; Pettijohn; Tallman; Travis; etc.) plus a rush for turbidity currents threatens to give petroleum geologists the usual hangover that follows the hasty misuse of poorly understood exploration methods. Indeed:

1. There are *four* major detrital rock series (or "clans") depending upon *inherited* mineral composition. These are orthoquartzites, low rank or common graywackes, high rank or feldspathic graywackes, and arkoses. They are respectively related (Krynine 1941–1955) to geotectonic types I and I_m; II_d and II_f; III and IV.
2. Types I, II, and IV may show internal mineralogic and textural development sequences, either strictly positional, or conventionally chronologic (so called "maturing," a somewhat loose term).
3. *All major types* may contain "silty or clayey" and "poorly sorted" *bimodal* rocks fully analogous to igneous porphyries. These may show graded bedding irrespective of rock type.
4. *Low rank or common graywackes* are very low in feldspar (less than 10 percent as a mean), and carry *enromous* initial loads of micas and hydromicas, either as discrete particles ("clay") or as slate-phyllite-schist rock fragments. They are thus skewed toward the finer sizes, complete with all derived second- and third-order properties. Genetically these are basically shallow water, near-shore sediments. Turbidity currents, if any, are within *ordinary deltas*. Low rank graywackes are totally *primary* (not the product of sequential differentiation of any other rock type!). They probably contain most of the oil and are the most abundant single sedimentary rock.
5. *High rank or feldspathic graywackes* are both primary and *terminal* at the same time. They are the only sedimentary rock series that shows *no* development sequence and are thus *not* ancestral to subgraywackes (Pettijohn 1949) or to arkose (Pettijohn 1954). These rocks are rare (fortunately) and are petroliferously bone dry.
6. The term graywacke, in its proper petrographic (i.e. mineral compositional) sense, was used by Lyell before 1839, by Nauman in 1850, and was revived in its classical sense by Krynine in 1937, thus giving him priority in the modern usage of the term.
7. "Sedimentary porphyries" cut across *all* major rock types; arkoses may carry 35 percent of kaolinitic matrix and quartzites 20 percent of quartzoes silt matrix. Hence it is against scientific principles. as done by some of the writers mentioned above, to refer to such a porphyry as a "graywacke" (regardless of composition) and in the next breath to call a micaceous sediment also a graywacke (regardless of texture). Thus the textural usage of the term "graywacke" is rejected. The name graywacke was and should remain a first order, i.e. compositional, term. Texturally poorly sorted, bimodal rocks are porphyries and nothing else!
8. The term "subgraywacke" is even more confusing, having been founded on the genetic misconception that type III leads to type II. Being symbolic of this confusion it is also rejected. So is the term "lithic graywacke," because the basic variable is mica, not rock fragments.
9. Detailed petrographic work by this writer on ancient sediments from all parts of the world and on recent deep sea sands from the Atlantic contradicts the idea that graywackes (in any sense, either compositional or porphyritic!) were formed on any large or even moderate scale in highly viscous fluids, alleged to be turbidity currents. Furthermore, a critical examination of Kuenen's technique in his famous turbidity current experiment opens its validity to the gravest doubts.
10. Finally it must be understood that upon the four basic compositional detrital rocks there may be superimposed an enormous number of local textural variations. These are the "phases" of Krynine's sedimentary "systems" (1955), which can be finally reduced to Otto's sedimentary units. The geotectonic control of the emergence, preferred associations and effectiveness of these sedimentary loci is marked, but definitely indirect. This is the "determining background" concept of Krynine (1947). Oversimplifications in this field of the so-called depositional "sedimentary tec-

tonics" are dangerous and considerable overhauling is needed.

2. PETROLOGIC ANALYSIS OF A STRATIGRAPHIC TYPE OIL FIELD IN WEST CENTRAL TEXAS

MORTON K. BLAUSTEIN
Baltimore, Maryland

The Lindemann (McMillan Sand) Oil Field, Runnels County, Texas, is located on the Eastern Platform of the Midland Basin. It contains two separate reservoirs, the Upper and Lower McMillan sandstones of Cisco (late Pennsylvanian) age. Oil accumulation is controlled primarily by stratigraphic conditions.

The present study explores the possibility of determining the nature of oil accumulation in such a field by combining a detailed quantitative petrologic analysis of the reservoir rock with subsurface structural mapping.

The study is based on 309 thin sections from 43 wells. Approximately half of these thin sections are from five cored wells, the remainder being from drilling samples in wells which were not cored. The relative quality of these two types of thin sections is analyzed in detail and it is concluded that, in general, both types of material give excellent usable data.

Thin sections of the reservoir rock quite accurately reflect the productive potentialities ofs the unit. The sandstone, which includes a conglomeratic facies, is generally fine-grained to very fine-grained, and well sorted; the principal cements are calcite, quartz, and clay. Porosities and permeabilities are favorable for fluid transmissibility.

The principal trap-making elements in the Lindemann (McMillan Sand) Field are:

1. The updip pinchout of the reservoir rock.
2. Structural closure against this pinchout, caused by compaction of the reservoir rock and the underlying shales over a limestone reef.
3. Stratigraphic variations in the reservoir, petrologic in nature, which locally determine the productive and barren portions of the field area.

The petrologic parameters which act as porosity trap-making elements are (1) grain size, (2) grain-size sorting, (3) calcareous cement, and (4) clay cement. These parameters have been studied in thin section, reduced to quantitative data, and mapped. The maps explain the reservoir conditions and productivity of the Upper McMillan sandstone.

A retroactive analysis of the field, from the date of discovery, indicates that if the petrologic study had been made during the development of the field, it would have proved helpful in indicating directions in which to drill and in avoiding dry holes.

The author believes that if the method employed in this study is extended to the analysis of other fields and to dry hole failures between fields, it will eventually be possible to combine sufficient regional information to be useful in the effort to detect regional stratigraphic trends. Such new trends might point to favorable areas for exploratory drilling.

3. PERMEABILITY LOSS FROM SWELLING OF MATRIX CLAYS IN SUB-GRAY-WACKES

G. HARVEY HAMILTON AND GEORGE R. DOWNS*
Union Oil Co. of California, Denver, Colorado; Consulting Geologist, Denver, Colorado

Fresh water coming in contact with the matrix clays of subgraywackes causes the clays to deflocculate and reduce the permeability of the rock to a small fraction of its original value. This process may form a seal which is adequate to trap gas in the down-dip portion of an outcropping potential reservoir bed.

In the southern Piceance basin of western Colorado, gas has recently been discovered in a gentle syncline where no conventional type of structural or stratigraphic trap is apparent. In this area, surface waters freely come in contact with the outcrop of the producing beds. In the discovery well, a reservoir pressure ranging from 750 to 1000 pounds was anticipated, based on the projection of the hydrostatic gradient from the outcrop to the reservoir at the well bore. Actual measured pressures proved to be in excess of 2300 psi, demonstrating an effectively confined gas reservoir. There was no apparent lithologic difference between the rock in the reservoir and at the outcrop, except for the expanded matrix clay at the outcrop.

Laboratory core permeability determinations showed that the reservoir rock (a subgraywacke) had air permeability of 0.3 md. and 9.5% porosity. Upon artificial introduction of fresh water into the core plug, the permeability was immediately reduced to 0.0037 md. It is proposed that dipping, truncated, sub-graywackes may form an effective, but generally unrecognized type of stratigraphic trap—one which invites exploration. This method of gas entrapment provides a reasonable explanation for gas accumulation in certain fields, previously considered to be due to vaguely defined "permeability changes" in the reservoir rock.

4. DIFFERENTIAL COMPACTION OF PENNSYLVANIAN SEDIMENTS IN RELATION TO SAND-SHALE RATIOS, JEFFERSON COUNTY, ILLINOIS

JOSEPH C. MUELLER† AND HAROLD R. WANLESS
Continental Oil Company, Oklahoma City, Oklahoma; University of Illinois, Urbana, Illinois

In Jefferson County, in the Illinois coal basin, southern Illinois, the Pennsylvanian column

* Person presenting paper.
† Person presenting paper.

between the Shoal Creek and Stonefort limestones, an interval of about 900 feet, was divided into seven intervals separated by widespread coals or limestones readily recognized on electric logs, namely the Shoal Creek limestone, coal No. 8, West Franklin limestone, coal No. 7, coal No. 5, coal No. 4, coal No. 2, and the Stonefort limestone listed in descending order. These intervals were determined from 578 electric logs in the county, an average of about one per square mile. Sand-shale ratios were determined for each interval and it was found that a "channel" sandstone of one age occurs in each interval except between the Shoal Creek limestone and coal No. 8. Two ages of channels occur in one interval. Sand-shale ratio maps were made of each interval. Thicknesses of each interval were compared in the "channel" areas and nearby, outside the channel, to avoid regional variations in thickness. Assuming that the coals and limestones were laid down nearly parallel to each other, variations in interval result from greater compaction of the shales than of the sandstones. Results show the following percentages of differential compaction for the six intervals with channels listed in descending order: 21, 34, 29, 35, 42 and 54 percent.

5. CLAY-MINERAL COMPOSITION OF RECENT SEDIMENTS FROM THE MISSISSIPPI RIVER DELTA

W. D. Johns, Jr.* and R. E. Grim
University of Illinois, Urbana, Illinois

Detailed clay mineral analyses of several hundred samples from the eastern and southern part of the Mississippi River Delta show montmorillonite as the most abundant component with smaller amounts of illite and chlorite or kaolinite. In general, the abundance of montmorillonite is highest in the river and nearshore samples and lowest in the off-shore samples. Modifications of this generality are presented and their possible causes are discussed.

The significance of the abundance of montmorillonite in relation to the character of the source area and the composition of other marine sediments is discussed. Consideration is given to the effect of differential flocculation, detailed variation in the source material, and diagenetic processes on the clay mineral distributions.

6. ENVIRONMENTAL CONDITIONS AFFECTING THE DEPOSITION OF BEACH SANDS BETWEEN VIRGINIA AND FLORIDA

Suzanne F. Bershad† and John K. Duncan
Division of Oceanography, U. S. Navy Hydrographic Office, Washington, D. C.

The prime purpose of this study was to correlate observed environmental conditions with beach deposits by the collection of 127 beach samples at 48 locations along the Atlantic and Gulf of Mexico coasts between Cape Henry, Virginia and Panama City, Florida. Locations sampled were spaced at approximately 50-mile intervals. With each sample, observations were made of the slope, strike, and character of the beach and wind and wave states. The effects of tide stage and of land and submarine topography on beach deposits were studied. A detailed laboratory analysis of samples and sub-samples was made to determine their mechanical, mineral, and mass properties. The increase in shell content of the beach deposits from north to south substantiates previous studies of the Atlantic Coast beaches. Variations in median grain size between stratified layers of some samples were found to be as great as the variations between samples from widely separated locations, or from any part of the same beach profile.

7. MIDDLE PALEOZOIC TECTONIC HISTORY OF NORTH-CENTRAL AND NORTHWESTERN UTAH

James E. Brooks
Southern Methodist University, Dallas, Texas

Regional studies of middle Paleozoic stratigraphy in north central and northwestern Utah indicate the presence of two major tectonic elements which controlled the distribution and duration of areas of deposition and non-deposition and/or erosion in the area during this time interval. These elements were: (1) stable shelf, in the southeastern part of the discussion area in the region of the present western Colorado Plateau; (2) miogeosyncline, peripheral to the shelf on the north and west and separated from the shelf by a narrow transition zone. Localized areas of varying degrees of tectonism are recognized along the strike of the geosyncline.

The major hiatus which exists on the shelf between uppermost Devonian or lowermost Mississippian rocks and Cambrian strata obscures the tectonic behavior of the shelf during the intervening portion of geologic time. Study of several adjacent stratigraphic sections within the geosyncline demonstrates the existence of several hiatal breaks of much shorter duration. These breaks may be traced shelfward with increasing temporal values until they merge with the major shelf discontinuity. Similarly, rock units bounded by these hiatuses persist with little lithic change toward the shelf and are typically completely removed by erosion by the time the transition zone is reached. The regional extent and lateral change in duration of the hiatuses together with the extent and lithology of the intervening rock units constitute a valid basis for interpreting the tectonic behavior of the stable shelf during the time now represented by unconformity.

8. TRIASSIC IN THE EASTERN GREAT BASIN

David L. Clark,* and William Lee Stokes
University of Iowa, Iowa City, Iowa: University of Utah, Salt Lake City, Utah

New data concerning Triassic stratigraphy in

* Person presenting paper.
† Person presenting paper.

the eastern part of the Great Basin have been obtained from previously undescribed sections in the western Utah-eastern Nevada area. These sections contain information regarding the western Utah-eastern Nevada part of the Triassic miogeosyncline, its deformation, stratigraphic relations and associated fauna. The Triassic is the youngest marine sequence presently known in this area, and it lies disconformably on Permian strata. Overlying Tertiary and Recent rocks consist of volcanics and alluvial material.

The only definite Triassic age assignment in this area is established on the occurrence of the Lower Triassic *Meekoceras* zone in the basal part of the section. Correlation with Triassic strata in western and central Nevada, southern Idaho, and Utah is based primarily on a similar occurrence of this assemblage. Above the *Meekoceras* zone there are several thousand feet of supposed Triassic sediments which have not been dated exactly. However, conodonts are known to occur above the *Meekoceras* interval and may prove to be of value in correlation. Other fossils are rare and are probably not diagnostic.

Thousands of feet of dense limestone, shaly calcarenite, and shale, all regarded as of Triassic age, are present in the area extending from the Wasatch Mountains of Utah to central Nevada. Evidently the eastern part of the Great Basin was more stable during the Triassic than areas to the north and west where very thick sections occur. However, local high areas in northeastern Nevada during the Triassic are indicated by coarse clastics, present in several sections.

There is evidence to support the existence of a positive element in southeastern Nevada during and after the Triassic period. The absence of Triassic sediments in the area, a Triassic outcrop pattern around the area, and presence of flanking red beds may be explained in this fashion.

Thursday, April 26, 1:45 P.M.
Waldorf Ballroom, Hilton Hotel

GENERAL PALEONTOLOGY AND STRATIGRAPHY

Presiding: R. V. HOLLINGSWORTH, Paleontological Laboratory, Midland, Texas, AND FRANK H. T. RHODES, University of Illinois, Urbana, Illinois

1. THE IDENTIFICATION OF OSTRACODE GENERA AND SPECIES IN THIN SECTIONS

STUART A. LEVINSON
Humble Oil and Refining Co.,
Houston, Texas

Recent research has revealed that a number of Paleozoic ostracode genera and species can be identified in thin section. This is possible because certain shell structures have been found to be constant within ostracode genera and species. Identifications in thin section are based on such characteristics as shell thickness, shell layering and the nature of the individual layers, types of overlap, and the expression in thin section of ridges, frills, spines and sulci.

The results so far attained do not indicate any modification of taxonomic groups; however, there is a suggestion that some closely related species of a few genera, especially *Bairdia*, may be conspecific. The further development of this thin section technique will facilitate the identification of these small fossils in cores and large fragments of well cuttings.

2. A FAUNULE OF UNUSUAL NONMARINE OSTRACODA FROM THE PLIOCENE OF IDAHO

DANIEL J. JONES,* AND NORMAN R. ANDERSON
University of Utah, Salt Lake City, Utah

The fluvio-lacustrine sediments of the Pliocene Idaho formation have yielded a prolific faunule of most unusual ostracodes from a locality 60 miles south of Boise, in Owyhee County, Idaho. Forms represented include highly ornate and spinose species of *Candona*, *Cyprios*, *Limnocythere*, *Ilyocipris*, *Cytherissa*, *Tuberocypris*, *Tuberocyproides*, and *Darwinula*. The faunule occurs in fine-grained siltstones, with abundant gypsum crystals and oolites. The lake(s) in which the ostracodes lived was probably quite shallow, and subject to periodic and significant changes in volume, area, and concentration of dissolved salts. Periodic decreases in the volume of water may have been significant in the development of the bizarre ornamentation of the Ostracoda. Two new genera and several new species are described and illustrated.

* Person presenting paper.

3. CONODONTS FROM THE TYPE CHESTER, ILLINOIS

CARL B. REXROAD
Texas Technological College,
Lubbock, Texas

The presence of conodonts in the rocks of the type Chester area has been known for some time. A study was undertaken to evaluate their use as Chesterian guide fossils in the expectation that they would prove valuable aids in correlations of other strata with the type section.

The shales and thin, interbedded limestones of the complete stratigraphic sequence were carefully sampled. Conodont-producing zones were found in every other formation. These formations are the Renault, Paint Creek, Golconda, Glen Dean, Vienna, Menard, Clore, and Kinkaid.

The fauna consists of 27 identified species be-

longing in nine genera, and three additional genera are known from fragments. The genera present are *Cavusgnathus*, *Cladognathus*, which is a new genus *Gnathodus*, *Hibbardella*, *Hindeodella*, *Ligonodina*, *Ozarkodina*, *Prioniodus*, *Spathognathodus*, *Subbryantodus*, *Synprioniodina*, and *Trichonodella*. Single specimens or groups of fragments represent the polygnathids and two apparently new genera. This fauna is distinct from lower and middle Mississippian assemblages and from the Pennsylvanian. Species will be more useful than genera in subdividing the series. In order further to evaluate conodonts as a tool for stratigraplc analysis of the Chester Series, additional researches on the Glen Dean formation of Kentucky and Indiana as well as of Illinois are in progress.

Conodont faunas similar to those of the type Chester series have been found in the Pella beds of Iowa, the Pitkin limestone of Arkansas and Oklahoma, the lower part of the Stanley shale of Arkansas and Oklahoma, the Barnett formation of Texas, and that portion of the Caney shale studied by Branson and Mehl.

4. UPPER DEVONIAN SUBSTAGES AND THEIR WORLD-WIDE CORRELATION ON THE BASIS OF CONODONTS

KLAUS J. MÜLLER
University of Iowa, Iowa City, Iowa

The Upper Devonian cephalopod limestones of Europe have yielded very rich conodont faunas, from which *Palmatolepis* has been studied extensively. The available representatives of this genus, about 4500 specimens, come from 70 localities, widely distributed over middle and western Europe, and they are from all five of the Upper Devonian stages that have been established on the basis of ammonoids. None of the 27 species present (of which 15 are new) occurs in all these stages, and some have a short vertical range. Since many species are close to or even conspecific with those which are present in North America, they are excellent for long-range correlation.

The conodonts confirm the belief that in the Upper Devonian of this country the correlatives of the *Manticoceras*-Stufe are widespread (e.g., the Genesee, Independence, Amana, Sweetland Creek, and Hackberry shales, as well as parts of the Ohio, New Albany, and Grassy Creek shales). Furthermore, equivalents of the *Cheiloceras*-Stufe and *Platyclymenia*-Stufe are present within the Ohio, New Albany, Grassy Creek, and Maple Mill shales, a correlation that has not been disclosed by ammonoids. Conodonts from equivalents of the *Oxyclymenia*-Stufe and *Wocklumeria*-Stufe are not known from America.

By the recognition of additional morphological features, the taxonomy of Devonian conodonts has been improved. Three subgenera are established, and they have biochronologic significance. An undescribed species of *Palmatolepis* (*Palmatolepis*) has a length of 4.5 mm. and is the largest conodont known to date.

There is now evidence that conodonts were enclosed by a combination of two different types of tissue; one produced the layer-by-layer structure of the conodont, and the other was merely a supporting tissue, which may have secreted another hard part, the "base." The "crimp" a new term, and the growth lamellae are discussed. They are regarded as evidence that there is a considerable change in form and pattern of sculpture within the development of each specimen, as well as a comparably wide range of variability of some features within the species.

Both the regeneration and the healing of broken parts are illustrated.

5. SPECIFIC VARIATIONS AMONG ARENACEOUS SILURIAN FORAMINIFERA FROM ILLINOIS*

HOWARD SCHWALB† AND CHARLES COLLINSON
Illinois State Geological Survey,
Urbana, Illinois

Arenaceous foraminifera are very abundant in Silurian strata of the Eastern Interior Basin and have considerable value as stratigraphic markers. Thousands of specimens from the 5-inch Superior Oil Co.-H.C. Ford et al., C.17 well core from White County, Illinois, show much more morphologic variation which is of little taxonomic significance. Among the coiled forms there is variation in the plane of coiling of whorls, deviation from the coiling habit, irregular inflation of the chamber, and duplication or triplication of the chamber. Among straight or curved forms there is difficulty in consistently identifying species due to variations of curvature, rates of expansion, and the lack of preservation of the proloculum. Recognition of these morphologically distinct but taxonomically insignificant variations is important in differentiation of species. The resulting clarification and reevaluation of species should increase the usefulness of these forms as stratigraphic indices.

6. ACANTHOCLADIA GUADALUPENSIS GIRTY, A POSSIBLE ALGALBRYOZOAN SYMBIOT

J. KEITH RIGBY
Brigham Young University, Provo, Utah

The bryozoan, *Acanthocladia guadalupenis* Girty, and the alga, *Solenopora texana* Johnson, consistently occur together in many thin sections of Permian limestone from Texas and New Mexico. *Solenopora* apparently forms the entire minutely cellular reverse side of *Acanthocladia* and consists of small radiating, unchambered but branching, tubules. These tubules ultimately connect at their bases with a "canal" system which surrounds the zooecial wall. This close relationship between bryozoans and algae indicates that the pinnate *Acanthocladia* is probably an algal-bryozoan symbiot.

Cellulose peels prove more useful for detailed

* Published with permission of the Chief, Illinois Geological Survey.

† Person presenting paper.

observation than do thin sections, for the peels show distribution of structure on a nearly plane surface.

7. DENDRASTER: A PROBLEM IN ECHINOID TAXONOMY

D. M. RAUP

Harvard University, Cambridge, Massachusetts

Intraspecific variation in the echinoid genus *Dendraster* is studied by means of a statistical analysis of variation in the living species, *D. excentricus*. The character "eccentricity" is analyzed in samples from thirty-four collections of *D. excentricus*. This character is prominent in current classifications of the genus.

It is found that observed eccentricity data are biased by an allometric relation between eccentricity and test length. This allometry is described by an empirically derived curve. The parabolic function defining this allometric curve is used to eliminate the length bias from the eccentricity data.

No systematic geographic variation is recognized in *D. excentricus* as reflected in the character eccentricity. However, the species may be divided into two ecological races on the basis of eccentricity. The race inhabiting sheltered bays is significantly less eccentric than the race living along the open coast.

The eccentricity data for *D. excentricus* is employed in a review of the classification of the fossil members of the genus. The heretofore unrecognized allometry and ecological variation in *Dendraster* may explain some of the difficulties encountered in the fossil classification. It is found that there are greater differences in eccentricity between populations of *D. excentricus* than there are between species in the fossil record.

ANNUAL BUSINESS MEETING

The annual business session of the Society was called to order at 4:30 P.M., Tuesday, April 24, by Francis J. Pettijohn, president, who introduced the officers for the new year as follows: President, Robert R. Shrock; Vice-President, Richard V. Hollingsworth; Secretary-Treasurer, Samuel P. Ellison, Jr., Editor of the *Journal of Paleontology*, William M. Furnish; and Editor of the *Journal of Sedimentary Petrology*, Jack L. Hough. Pettijohn remains a member of the Council as Past-President.

It was moved, seconded, and carried that the minutes of the 1955 meeting be approved as published in the *Journal of Paleontology*, Volume 29, Number 4 (July, 1955).

The following reports were given.

1. *Report of the 1955 Society's Editors for the Journal of Paleontology* (*A. K. Miller and W. M. Furnish*).—Volume 29 of the *Journal of Paleontology*, issued in conjunction with The Paleontological Society, contains a total of 1084 pages and 108 collotype plates. There are 58 papers plus paleontological notes, nomenclatural notes, reviews, and an author-subject index. Society records, miscellaneous notices, and abstracts of meetings are also included.

This volume represents an increase of 196 pages and 8 collotype plates over the preceding one. It also exceeds a ten-year average by 260 pages and 4 plates. The March, July, and November issues (sponsored by the S.E.P.M.) total 496 pages and 36 collotype plates; representing an increase of 38 pages of text and a decrease of 12 plates from that in corresponding issues of Volume 28. Most manuscripts have been published within nine months after being received; those on hand have maintained the margin.

In the S.E.P.M. issues of Volume 29, there are twenty-seven papers, inclusive of Paleontological Notes. Nine were contributed by authors outside North America. A variety of subjects are treated, but the majority, seventeen, deals primarily with systematic descriptions of fossil or living animals. There are three studies on taxonomy and three on biostratigraphy; one is a bibliography, and three are chiefly concerned with ecology. Emphasis has been placed upon the descriptive and applied aspects of micro-organisms—fourteen of the twenty-seven titles and some 70% of the total text. Papers primarily devoted to descriptions of Foraminifera and Ostracoda constitute nine titles and some 50% of the over-all text as well as two-thirds of the plates. Studies are about evenly divided between Paleozoic and post-Paleozoic. Eight reviews of current literature and three nomenclatural notes were published.

Miller relinquished duties as co-editor on January 1, 1956. Furnish assumed full responsibility at that time and also attended The Paleontological Society council meeting in New Orleans as official representative of

the S.E.P.M. The State University of Iowa contributed financial assistance in the form of miscellaneous supplies and expenses.

2. *Report of the Editor of the Journal of Sedimentary Petrology (Jack L. Hough).*— The *Journal of Sedimentary Petrology* was published in 1955 under the direction of Acting Editor Ralph E. Grim, as volume 25, numbers 1 through 4. Each number contained 80 pages. Seventeen hundred copies of the first three issues were printed, and nineteen hundred copies of the fourth issue were printed. The contents of the volume included 32 technical articles, one note, two discussions, two reviews, 3½ pages of announcements, abstracts of papers given at the 1955 S.E.P.M. meeting in New York, and an index. Three and a half pages of advertisements of Society publications were run. The distribution of articles, notes, and discussions according to national origin was as follows: United States, 33; Italy, 1; and Japan, 1.

The backlog of manuscripts has increased, during the latter part of the year, to a size which makes a further expansion of the *Journal* highly desirable. As may be seen in the report of the Secretary-Treasurer, the net income of the *Journal* was over $1200.00.

As in the past six years, the University of Illinois has provided a half-time editorial assistant.

J. L. Hough, Editor, returned to his regular duties at the University of Illinois in September, after 18 months absence on an assignment as Head of the Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, India. Responsibility for acceptance of manuscripts and other matters in the later part of 1955 and early 1956 is divided between Acting Editor Grim and Editor Hough.

3. *Report of the Secretary-Treasurer* (Samuel P. Ellison, Jr.).—

BACK VOLUME SALES

(January 1, 1955, to December 31, 1955)

Journal of Paleontology, Volumes 1–29	$4,265.56
Journal of Sedimentary Petrology, Volumes 1–25	850.32

SPECIAL PUBLICATION SALES

(January 1, 1955, to December 31, 1955)

Turbidity Currents	$ 210.75
Recent Marine Sediments	$3,607.00
Finding Ancient Shorelines	$2,958.45

PRINTING AND ENGRAVING BILLS FOR 1955

Journal of Paleontology

	Banta Printing Bills		*Meriden Engraving Bills*	*Total Printing and Engraving Bills*	*S.E.P.M. Total Printing and Engraving Bills*
	Printing	*Postage*			
Number 1 (Jan.)*	$ 2,991.74	$ 93.15	$1,090.82	$ 4,175.71	
Number 2 (Mar.)	2,319.14	55.25	234.37	2,608.76	$2,608.76
Number 3 (May)*	3,551.72	109.24	1,156.37	4,817.33	
Number 4 (July)	3,199.83	91.62	467.33	3,758.78	3,758.78
Number 5 (Sept.)*	2,672.24	93.82	885.28	3,651.34	
Number 6 (Nov.)	2,484.01	81.76	867.93	3,433.70	3,433.70
	$17,218.68	$524.84	$4,702.10	$22,445.62	$9,801.24
1954 Totals	$14,771.40	$447.17	$4,183.75	$19,402.32	$9,714.11

* Odd numbers paid by Paleontological Society.

Journal of Sedimentary Petrology

	Banta Printing Bills		
	Printing	*Postage*	*Total*
Number 1 (March)	$1,274.93	$ 66.73	$1,341.66
Number 2 (June)	1,174.85	85.14	1,259.99
Number 3 (September)	1,222.39	85.58	1,307.97
Number 4 (December)	1,364.91	91.13	1,456.04
	$5,037.08	$328.58	$5,365.66
(1954 Totals)	$4,707.49	$268.37	$4,975.86

MEMBERSHIP, MAILING, AND JOURNAL STATISTICS

	Dec. 31, 1955	Dec. 31, 1954	Dec. 31, 1953
1. S.E.P.M. Membership:			
Active Members	895	751	635
Associates	285	310	305
Correspondents	5	5	5
Honorary Members	3	1	1
TOTAL	1,188	1,067	946
2. *Journal of Paleontology* Mailing List:			
S.E.P.M. Active & Honorary Members	485	434	383
S.E.P.M. Associates	155	165	177
Subscribers	722	684	692
P.S. Members	610	612	566
TOTAL	1,972	1,895	1,818
3. *Journal of Sedimentary Petrology* Mailing List:			
S.E.P.M. Active & Honorary Members	607	483	402
S.E.P.M. Associates	171	183	186
S.E.P.M. Correspondents	5	5	5
Subscribers	806	740	671
TOTAL	1,584	1,411	1,264
4. Edition, *Journal of Paleontology*	2,200	2,200	2,100
5. Edition, *Journal of Sedimentary Petrology*	1,800*	1,700	1,400
6. Number of Pages, *Journal of Paleontology*	1,084	888	910
7. Number of Plates, *Journal of Paleontology*	108	100	91
8. Number of Pages, *Journal of Sedimentary Petrology*	317	298	301
9. New Members	161	133	76
10. Transfers to Active Membership	47	44	2
11. Members and associates dropped for non-payment of dues	16	28	37

* 1,900 copies beginning with December, 1955.

FINANCIAL STATEMENT FOR THE YEAR ENDED DECEMBER 31, 1955

CERTIFICATE OF INDEPENDENT PUBLIC ACCOUNTANTS

The Council, Society of Economic Paleontologists and Mineralogists:

We have examined the balance sheet of Society of Economic Paleontologists and Mineralogists at December 31, 1955 and the related statement of income and surplus for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the accompanying balance sheet and statement of income and surplus present fairly the financial position of Society of Economic Paleontologists and Mineralogists at December 31, 1955 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

ARTHUR YOUNG & COMPANY

Tulsa, Oklahoma, January 13, 1956

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
BALANCE SHEET, DECEMBER 31, 1955

ASSETS	Total	General Fund	Publication Fund
CURRENT ASSETS:			
Cash	$23,462.14	$19,188.37	$4,273.77
Savings account	2,608.48	2,608.48	—
Accounts receivable	96.25	93.50	2.75
Total current assets	$26,166.87	$21,890.35	$4,276.52

PUBLICATIONS:			
Journal of Paleontology:			
Issues prior to 1955—14,066 journals at 50¢ each (2,233 complete volumes)	$ 7,033.00	$ 7,033.00	$ —
Issues 1 to 6 of 1955—1,212 journals, at cost	2,144.93	2,144.93	—
Reprints in 1948, Volume 1, 1927—729 volumes, at cost.	1,592.19	1,592.19	—
Journal of Sedimentary Petrology:			
Issues prior to 1955—2,371 journals at 50¢ each (690 complete volumes)	1,185.50	1,185.50	—
Issues 1 to 4 of 1955—634 journals, at cost	504.52	504.52	—
Special publications:			
Turbidity Currents, 496 issues, at cost	424.13	—	424.13
Recent Marine Sediments, 1,175 issues, at cost	2,424.61	—	2,424.61
Total publications	$15,308.88	$12,460.14	$2,848.74
FURNITURE AND FIXTURES (less reserve, $1,769.26)	$ 1.00	$ 1.00	$ —
DEFERRED CHARGES	$ 1,077.74	$ 100.84	$ 976.90
	$42,554.49	$34,452.33	$8,102.16
LIABILITIES AND SURPLUS			
CURRENT LIABILITIES:			
Accounts payable	$ 2,575.37	$ 2,575.37	$ —
Amount payable to Paleontological Society	2,805.86	2,805.86	—
Accrued printer's charges	2,287.78	1,400.00	887.78
Total current liabilities	$ 7,669.01	$ 6,781.23	$ 887.78
DEFERRED CREDITS:			
Subscriptions to journals—net of portion to be received by Paleontological Society	$ 6,417.68	$ 6,417.68	$ —
Subscriptions to special publications	2,958.45	—	2,958.45
Membership dues for 1956 and 1957	7,380.80	7,380.80	—
Total deferred credits	$16,756.93	$13,798.48	$2,958.45
SURPLUS PER ACCOMPANYING STATEMENT	$18,128.55	$13,872.62	$4,255.93
	$42,554.49	$34,452.33	$8,102.16

(*See also facing page*)

4. *Report of the Research Committee* (*Raymond Siever, Chairman*).—The members of this committee, as of April, 1955, were O. L. Bandy, W. C. Bell, B. Kummel, H. A. Lowenstam, E. D. McKee, R. H. Nanz, F. J. Pettijohn, W. J. Plumley, R. Siever, L. L. Sloss, H. E. Summerford, C. Teichert, F. B. Van Houten, and L. E. Workman.

At the annual meeting of the committee in 1955, the topic, "Directional Properties of Sedimentary Rocks," was selected for the symposium to be presented at the 1956 meeting. The general principles governing the choice of papers were that a fairly broad coverage of the topic be insured and that presentations should be of new material. Speakers invited were E. D. McKee, G. Rusnak, J. R. Curray, L. C. Bonham, J. E. Sanders, and A. Carozzi. Subjects discussed were experimental production of crossbedding, relation of grain shape fabrics to crossbedding, grain shape fabrics of modern sediments, turbidity current directional structures, and studies of various directional properties in some California sediments and in the sediments of an Alpine basin. This symposium may be published as a special volume.

This year the Research Committee selected two outstanding papers in the *Journal*

(*Continued on page 198*)

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
STATEMENT OF INCOME AND SURPLUS
YEAR ENDED DECEMBER 31, 1955

	Total	*General Fund*	*Publication Fund*
INCOME:			
Membership dues and subscriptions:			
Journals of Paleontology and *Sedimentary Petrology*	$ 3,920.00	$ 3,920.00	$ —
Journal of Paleontology	12,946.03	12,946.03	—
Journal of Sedimentary Petrology	6,889.76	6,889.76	—
	$23,755.79	$23,755.79	—
Sales of special publications:			
Turbidity Currents	$ 210.75	$ —	$ 210.75
Recent Marine Sediments	3,607.00	—	3,607.00
	$ 3,817.75	$ —	$ 3,817.75
Sales of back numbers:			
Journal of Paleontology, Volumes 1 to 29	$ 4,265.56	$ 4,265.56	—
Journal of Sedimentary Petrology	850.32	850.32	—
	$ 5,115.88	$ 5,115.88	—
Sales of plates	$ 462.97	$ 462.97	$ —
Advertising	$ 532.82	$ 532.82	$ —
Donations ($4,683.64 from The American Association of Petroleum Geologists)	$ 5,567.92	$ 4,683.64	$ 884.28
Miscellaneous	$ 265.17	$ 265.17	$ —
	$39,518.30	$34,816.27	$ 4,702.03
Less: Proportion of 1955 income accrued to Paleontological Society	2,404.45	2,404.45	—
COSTS AND EXPENSES:			
Cost of printing:			
Journal of Paleontology	$10,546.00	$10,546.00	—
Journal of Sedimentary Petrology	4,977.03	4,977.03	—
Recent Marine Sediments	4,166.29	—	$ 4,166.29
	$19,689.32	$15,523.03	$ 4,166.29
Expenses:			
Clerical salaries	$ 6,129.74	$ 6,129.74	$ —
Office supplies	459.70	459.70	—
Postage and express	1,461.81	1,197.58	264.23
Office rent	1,500.00	1,500.00	—
Telephone	113.45	113.45	—
Audit fee	200.00	200.00	—
Payroll taxes	171.61	171.61	—
Convention expense	283.92	283.92	—
Miscellaneous	754.14	636.00	$ 118.14
	$11,074.37	$10,692.00	$ 382.37
Adjustment for (increase) decrease in inventory of publications	$(1,514.94)	$ 834.42	$(2,349.36)
	$29,248.75	$27,049.45	$ 2,199.30
NET INCOME	$ 7,865.10	$ 5,362.37	$ 2,502.73
SURPLUS AT DECEMBER 31, 1954	10,263.45	8,510.25	1,753.20
SURPLUS AT DECEMBER 31, 1955	$18,128.55	$13,872.62	$ 4,255.93

of Sedimentary Petrology and the *Journal of Paleontology* for best paper awards. The award for the best paper in the *Journal of Sedimentary Petrology* for the year 1954 was given to "Sedimentary Framework of the Modern Mississippi Delta" by H. N. Fisk, E. McFarlan, Jr., C. R. Kolb, and L. J. Wilbert, Jr. (deceased). The award for the best paper in the *Journal of Paleontology* for the year 1954 went to "Quantitative Studies of Brachiopods from the Lower Carboniferous Reef Limestones of England" by Donald Parkinson. These awards were presented at the joint session of the A.A.P.G.-S.E.P.M. by Raymond Siever, Chairman of the Committee.

The Research Committee presented to the Council by unanimous vote the nomination of Raymond C. Moore as an Honorary Member of the Society. The Council approved and the presentation was made at the joint annual meeting by J. M. Weller.

The committee has sought means to stimulate research in addition to the arranging of symposia at annual meetings. As an experiment, the chairman and others in the North-central states organized a small, regional, informal one-day meeting with the purpose of bringing together active research workers to exchange ideas and discuss research problems in an informal conference atmosphere. It is hoped that in the next year similar meetings will be organized by members of the committee in various parts of the country. These meetings may pave the way for having more-or-less regular meetings of research groups in various parts of the country with fluid programming in which there can be a free interchange of ideas.

At the close of the 1956 meeting Curt Teichert took over the duties as Chairman of the Committee.

5. *Report on the Earth Sciences Division of the National Research Council* (*F. J. Pettijohn, S.E.P.M. Representative*).—The program of the Division of greatest interest to members of S.E.P.M. probably is that of the various Division committees, especially the Advisory Committees for screening candidates for National Science Foundation Fellowships—both predoctoral and postdoctoral. The technical committees whose activities are of greatest interest to sedimentologists and paleontologists include the Committee on Clay Minerals, the Committee on Stratigraphy and the Committee on the Treatise on Marine Ecology and Paleoecology. The Committee on Clay Minerals has sponsored a series of annual conferences on clay mineralogy, the proceedings of which are edited by members of the committee and published and distributed by the National Research Council. Both the Committee on Stratigraphy and the Committee on the Treatise have about completed their assignments. The former has issued a series of reports and correlation charts over the years which are familiar to all stratigraphers. The latter committee has completed its work on the *Treatise* which should soon be available for distribution. The Committee on Review Articles in Geology and Geophysics has been transferred to the Geological Society of America. The Committee on the Chemical Composition of Sediments has been discharged.

6. *Report on the American Geological Institute* (*F. J. Pettijohn*).—The By-Laws of S.E.P.M., as now revised, specify that the president and past-president shall be the Society representatives on the Board of Directors of the American Geological Institute. Your present representatives, therefore, are Hans E. Thalmann and myself. Dr. Thalmann is unable to be present at this meeting so the responsibility of reporting to you on the activities of A.G.I. is mine. Unfortunately, as I did not go to New Orleans and could not attend the Directors meeting my report is a second hand account.

The principal item to report, perhaps, is the greatly expanded circulation of the A.G.I. *Newsletter*. This publication is now sent without charge to all the members of all the affiliated societies. As a result, everyone is now conversant with the activities of the Institute, its plans and problems. Hence an extended report by me would be put a repetition of what readers of the *Newsletter* already know. The Institute is now able to report directly to its constituents.

The S.E.P.M. participates in Institute activities in several ways. In addition to the two directors mentioned above, it is represented on the Glossary Committee and on the Government Relations Committee.

Willard Pye was our representative on the Glossary Committee. At his request he has been replaced by Jules Braunstein who, with assistance of several others, has completed compilation of the terms and definitions pertaining to sedimentology and sedimentation. Norman Hinchey has recently been appointed our representative on the Government Relations Committee.

For reasons pointed out above, it seems unnecessary to render a detailed summary of Institute activities and accomplishments. But deserving of emphasis, even at the risk of repetition, is the problem of financing the Institute. Despite much thought and labor on this knotty problem, no adequate solution has been found. From its inception the A.G.I. has been financed on a shoestring and it has operated on a deficit budget since 1950–51. It is obvious that this state of affairs cannot long continue. Clearly the member societies, of which S.E.P.M. is one, who joined with the National Academy of Sciences and the National Research Council to form the Institute, must face up to the problem of providing adequate funds. If they are not willing to do so, the Institute faces bankruptcy.

It seems to your representative that we shall soon have to decide whether we really want a profession-wide organization devoted to geologists and their problems. Perhaps the issues have been confused and A.G.I. has been regarded as another geological society or an inter-society committee. Actually it is neither; its aims and objectives are professional rather than scientific. Its concern is geologists, not geology. Do geologists need an organization, comparable to the American Medical Association or the American Bar Association, concerned with professional ethics, employment of geologists, education and recruitment of geology students, licensing of geologists, public relations, the utilization of geologists in government and military affairs, and the like? If we do, we shall have to pay for it.

7. *Report of the Joint Committee on Invertebrate Paleontology* (*Raymond C. Moore*). —The Joint Committee on Invertebrate Paleontology is composed of 30 members chosen from the Society of Economic Paleontologists and Mineralogists, the Paleontological Society, and the Paleontographical Society for the purpose of guiding accomplishment of the project to publish a comprehensive, highly authoritative *Treatise on Invertebrate Paleontology*. Seventeen S.E.P.M. members (*Branson, Dunbar, *Frizzell, *Howe, *Howell, *Knight, Lalicker, *Miller, *Moore, *Newell, Reeside, Rolshausen, Shrock, *Stenzel, Swartz, Warthin, *Weller) belong to this committee and in addition the Society is represented by 41 contributing authors (10 from the preceding list marked by an asterisk and Barker, Bassler, Bell, Boardman, Durham, Furnish, Gardner, Glaessner, Hanna, Hatai, Hessland, King, Kummel, Levinson. Loeblich, Lowenstamm, Olsson, Palmer, Peck, Puri, Scott, Shaver, Sohn, Stainbrook, Stephenson, Swain, Tasch, Teichert, Thompson, Ubaghs, Youngquist). These, as well as all other authors and the Editor, receive no financial remuneration of any kind. The Geological Society of America has made grants for the *Treatise* project amounting to $35,000 and has aided some individual authors by grants totalling at least $5150; also, this Society is handling costs of publication and distribution on a basis of minimum possible charge for unit volumes as they are issued. Thus, taken all together, this is a collaborative undertaking of unparalleled magnitude.

A survey of the project as of April, 1956, comprising an inventory of both published and unpublished materials, indicates that the work of organizing the *Treatise* is approximately 60 percent accomplished, although only 5 of the 22 planned parts actually are published and available for use. These are Parts D (radiolarians, tintinnines), E (archaeocyathids, sponges), G (bryozoans), P (chelicerates, pycnogonids), and V (graptolites), which aggregate 928 pages with approximately 5415 individual figures. Each volume is priced at $3.00 (except P, at $3.50), with mailing cost included, and all orders are being handled by the Geological Society of America headquarters at 419 West 117th Street, New York 27, N. Y. Two parts which are now in press are F (coelenterates) and L (ammonoids); these will contain a total of nearly 1000 pages with approximately 6800 individual figures. Expected to be made ready for press during the first half of 1956 were

Parts C (foraminifers), O (trilobites), and Q (ostracodes), but delays of some authors in finishing their assignments indicate necessary postponement of publication. Several other units, however, are moving ahead about as well as can be expected and a few unhappily, at snail's place. The limiting factors in issuing volumes of the *Treatise* are the speed at which contributing authors are able and willing to finish their assignments, time available for editorial work (the editor has given nearly full time in many recent months), and capacity of the University of Kansas Press which has handled all setting of type and organization of published pages. Ultimately, the task will be finished, if not by the present Editor and those working with him, by others, for the status of the *Treatise* as an indispensible foundation for future studies in invertebrate paleontology is assured. Along with a statement of the present aim of carrying the project ahead as steadily as possible, a realistic forecast must point out that years, rather than months, will elapse before the last planned volume is issued.

Special mention should be made of assistance which has been furnished during 1954–56 by H. J. Harrington in advancing the volume on trilobites and during 1955–56 by P. C. Sylvester-Bradley in organizing the volume on ostracodes. Work by these men has been done while carrying on other tasks as visiting professors at the University of Kansas.

In summary, accomplishments are now appreciable and output of additional volumes of the *Treatise* at a reasonable rate seems to be assured. Progress mainly depends on the continued support of authors who are working together and of the Societies which jointly have underwritten the project.

Finally, it seems appropriate to report that several authors (at least 17), who have made no appreciable progress on their accepted commitments in the past 5 years, now seek to extend time for accomplishing their *Treatise* work to 1960 or even 1964, otherwise withdrawing from the project, and to record the fact also that critical review of received contributions generally has led to complete rewriting (for some texts 3 times), thus retarding completion of readiness for press. On some typescripts the Editor has spent as much or more time probably than that used by the author, leading to innumerable corrections of mainly nomenclatural nature. This entails extended correspondence but at length satisfactory conclusions are reached. Then the segment of *Treatise* material is approved for publication. In this connection, paleontologists generally may be interested in part of a letter sent to the Editor by one of the *Treatise* authors whose contribution has been or is being currently published: "Please accept my sincerest thanks for the trouble you took on my account in correcting numerous nomenclatural errors which would otherwise have lowered the value of my work. As it now is, I firmly believe that it (my *Treatise* chapter) will be a credit to us both, to me as author and to you as editor. And I wish to add in all sincerity how deeply I feel my obligation to you, a feeling which has not lost but considerably gained through our sometimes sharp disagreements in the course of preparing the manuscript. In one of your letters you remarked that you have made enemies as editor. Please do not count me as one of them but consider me as one of your friends." Such communications help to pay for behind-the-scenes labor in producing the *Treatise*.

8. *Report of the Advisory Committee on Radioactive Mineral Exploration* (*H. N. Fisk*).—Two meetings of the Advisory Committee on Radioactive Mineral Exploration were held since the 1955 Business Meeting of the S.E.P.M. Frederick H. Lahee was re-elected chairman and Cecil H. Green was elected vice-chairman at the first of these meetings which was held in Houston, Texas, on May 17, 1955. The types of radioactive detection instruments now being manufactured for sale was the main topic of discussion.

The status of cooperation between the Committee and the Atomic Energy Commission was reviewed at the second meeting held on October 28, 1955, in Dallas, Texas. It was reported that 476,000 feet of seismic shotholes had been logged in the Rocky Mountain Region by May, 10, 1955; of this total, 106,000 feet were logged by the oil companies using the Atomic Energy Commission's equipment, and 370,000 feet were logged by A.E.C. personnel with permission of the various companies. Information con-

cerning the utilization of logs of seismic shotholes for radioactive exploration in other regions is not available. Also discussed were the advantages and disadvantages of probing holes as contrasted with examination of cuttings brought up in the drilling of these holes.

9. *Report of the Representative on the Committee for the Glossary of Geologic terms, (Jules Braunstein).*—The present S.E.P.M. representative on the Glossary Project was appointed shortly after the first of 1956, following the resignation of the previous representative. Therefore, no meetings of the Committee have been attended, and no first hand report of the progress of the project can be made.

Several lots of definitions were received in January, which were the results of work by the former representative, as well as material compiled at the University of Iowa. All of these were checked for acceptability of usage, and citation of authorship, and many were rewritten. In this work, the writer was assisted by Robey Clarke, Roger Corbeille, and McLain Forman, all of New Orleans. The final group of new and/or revised definitions was sent to the Chairman of the Glossary Project in mid-February.

A number of definitions which should have been included in the S.E.P.M. portion of the Glossary may have been overlooked due to the shortness of time available between the appointment of the new representative and the stated deadline for submission of material. It is therefore recommended that the S.E.P.M. maintain a permanent Glossary Committee that will be responsible for compiling corrections and additions to the Glossary for publication as annual or biennial supplements.

10. *Report of Pacific Coast Section (W. H. Easton).*—The Pacific Section now has 250 members, most of whom are employed in southern California. The balance in the treasury is $1698.40, as reported by R. L. Pierce, Secretary-Treasurer.

The monthly Biostratigraphy Seminar, which is sponsored jointly by the S.E.P.M. and Bakersfield Evening School, is being continued this year with eight meetings on the program.

On February 19 the Pacific Section sponsored a one-day field trip to the type area of the Tejon formation (Eocene) in Live Oak Canyon. About 140 geologists attended. Leaders were S. Carlson and J. Bigelow. This was the first opportunity for general access to this important section in eleven years, inasmuch as it is on closed land.

On May 4 and 5 the Pacific Section will sponsor a field trip to the Huasna area near Santa Maria. The leader will be F. D. Crawford. Preliminary papers will follow a get-together and barbecue on May 4 in Santa Maria. This will be the first time that a field trip will have been arranged for the Santa Maria District. Important Miocene successions and complicated structures are exposed.

The Pacific Section will again cooperate with A.A.P.G. and S.E.G. at the Pacific Section Annual Meeting in Los Angeles on November 8 and 9. The annual dinner of the Pacific Section will be on November 8. A half-day technical session will be on November 9.

As usual, S.E.P.M. A.A.P.G., and S.E.G. sponsored a dinner dance near Christmas, the date being December 3 this year.

11. *Report of Gulf Coast Section (E. H. Rainwater).*—The Section is now in its third year, and has a membership of approximately 220, located in various parts of the Gulf Coastal plain. The aim of the Section, as set forth in the Constitution, is "to promote the science of stratigraphy in the Gulf Coast states through research in paleontology and sedimentary petrology." Membership is restricted to persons who are members or associate members of S.E.P.M.; associate members are those persons who otherwise qualify for membership but who are not members or associate members of S.E.P.M.

Membership dues are $1.00 per year. This income from dues is used to pay the cost of printing and mailing notices, newsletters, membership cards, and publications by the Section.

A constitution for the Section was adopted in 1954 and it provides, among other things, for:

1. An annual meeting, which "will usually be held in conjunction with the annual meeting of the Gulf Coast Association of Geological Societies." Our 1954 and 1955 business meetings were held during the annual meetings of the G.C.A.G.S.

2. An editor, appointed by the president, who "shall actively solicit papers from the Section membership for presentation at the annual meeting." Our editor already has commitments for three papers by members of the Section for presentation at the 1956 annual meeting of the G.C.A.G.S. in San Antonio, October 31–November 2, and for publication in the *Transactions*. The Gulf Coast Section of S.E.P.M. participated in the technical program of the 1954 and 1955 annual meetings of the G.C.A.G.S.

3. Business Representatives, appointed by the president, one from each local geological society affiliated with the Gulf Coast Association of Geological Societies. At present we have a business representative in each of the 12 local geological societies in the Gulf Coast who are actively engaged in soliciting papers for the annual meeting, recruiting new members for the Section, and keeping our members in the area represented informed of the activities and plans of the Section.

It is clear that the founders of the Section intended that it cooperate closely with the G.C.A.G.S. This could not be otherwise, as the Section's members are also members of the G.C.A.G.S. However, the organization and the objectives of the two societies are distinct, and it is possible that the Gulf Coast Section of S.E.P.M. will sometimes wish to hold its own session at the Annual Meeting. Also, the Section has underway some projects which are of special interest to its members. These are:

1. Improvement of well samples. A report on "Technique of Catching and Handling Well Samples," Special Publication No. 1 of the Section, was published in the *Oil and Gas Journal* and *World Oil*, and copies were sent to 280 companies who operate in the Gulf Coast. This report was written primarily from the viewpoint of micropaleontologists who work in the Gulf Coast Oligocene and Miocene belts. An expanded report, to include a description of the proper methods for obtaining samples in upper Gulf Coast wells, primarily for lithology and paleoecology, is now being prepared.

An objective of the Section, though not an active project, is to interest the state geological surveys in preserving a "master set" of cuttings and core samples from key wells.

2. The major project of the Section is the compilation of data on the type localities and type subsurface sections of all Mesozoic and Cenozoic stratigraphic units in the Gulf Coast. A list of over 300 such units has been prepared, and distributed to the membership. Many stratigraphers and paleontologists are now working on this project. It is our plan to publish the information on the type sections. A book of more than 300 pages will be required to include the data which we hope to assemble.

Field Trips

The Gulf Coast Section has arranged for two field trips to be conducted for its members during 1956—one to the classic Miocene localities in western Florida, May 3–5, and the other to Lower Cretaceous exposures in the San Antonio, Texas, area in early November.

General Objectives of the Section

The Gulf Coast Section is getting started at a time when there is renewed interest in paleontology and mineralogy, and it is hoped that the organization can help the stratigraphers, paleontologists, sedimentologists, palynologists ecologists, mineralogists, and petrologists gain proper recognition for their work. These scientists, whether in commercial work, with state or federal surveys, or in the academic field, have had little encouragement to carry on their studies in these basic earth science fields. The managers of the many oil and gas companies operating in the Gulf Coast have for many years considered that electric logs of wells and geophysical surveys of the areas of interest gave most of the information needed in exploring for oil and gas. One of the aims of the Section is to stress the importance of studying the rocks and the fossils, to help improve the conditions of the geologists engaged in this work, and to encourage young geologists to choose one of these branches of geology.

The long-range objective of the Gulf Coast Section is to gain an understanding of the detailed geological history of all parts of the Gulf Coastal plain. Many of the Section's members are making special studies of the sediments and fossils of the Gulf Coast, and will probably publish the results. Others

are active in many ways in carrying out the objectives of the Section.

12. *Report of the Permian Basin Section* (*Harold L. Williams*).—The Permian Basin Section of the S.E.P.M. sponsored a successful field trip, adopted a constitution, established two local sections that are very active, and conducted a successful membership drive in conjunction with the election of officers for the coming year. Financially, the Section started the year in debt; it ended the year with a modest balance in the bank.

Last October 21 and 22, the P.B.S. sponsored a field trip into the Guadalupe, Brokeoff, and Delaware Mountains of Texas and New Mexico. Under the leadership of Phillip B. King, Norman D. Newell and Donald W. Boyd, 250 geologists reviewed in the field some of the problems and aspects of the Guadalupe and Leonard sedimentation and stratigraphy of the basin, rim and shelf provinces of these Mountains. This successful field trip was the result of a great deal of work by a very small group of men who had a comparatively short period of time at their disposal. They were hampered not only by lack of time but by extremely hard rains in the Mountains which finally necessitated the rebuilding of some roads and the use of National Guard trucks to convey the party over some three miles of mountain roads that were impassable to the average vehicle. The burden of this work was carried by Walter C. Warren, Frank Dameron, Hugh N. Frenzel, Frederick L. Stead, and Walter W. Roye. They were assisted by M. R. Stipp, J. P. D. Hull, Jr., C. D. DiGiambattista, J. M. Alcorn, Don Caussey, Walter R. Berger, Jr., Clyde E. Harrison, Roy F. Milks, G. L. Wilde, and G. T. Schmitt. The P.B.S. is in debt to these 14 men for organizing this most successful field trip that was attended by many famous students of the Upper Permian.

The Constitution Committee, under Berte H. Haigh's chairmanship, wrote a constitution that was unanimously adopted by the Executive Council.

P.B.S. members in Fort Worth and Lubbock organized local sections that hold regular meetings. The Fort Worth group is single-handedly organizing the P.B.S. Annual Meeting to be held May 11 and 12. May 11 is to be devoted to papers and business meetings; May 12 is to be given to a one-day, one-stop, field trip that should be unique in this day of field trips that cover scores of miles. The entire day will be spent studying the geology of one small complex area.

At present the P.B.S. has 354 members, approximately the same as last year, and again one-half reside in Midland.

13. *Report on the Status of the Index to the First Twenty-five Volumes of the Journal of Paleontology* (*Hans E. Thalmann*).—The card indexing of the first twenty-five volumes of our *Journal* has been terminated, thanks to the efficient and unselfish efforts of the following volunteers, to all of whom the Society of Economic Paleontologists and Mineralogists is deeply indebted: Wolf Maync (Paris), Ralph L. Langenheim (Berkeley), Louise Jordan (Norman), Doris Malkin (Norman), Myra Keen (Stanford), Augusta H. Kemp (Seymour), and I. B. Gold (Los Angeles). Thousands of 3″×5″ cards are at present alphabetically sorted and bundled at Stanford to be used as a manuscript for the printer. This card-manuscript will be delivered, upon completion in the course of this year, to the Headquarters of the Society. The Index will contain all described and figured general, species, and subspecies (or varieties) published in the twenty-five volumes (1927 to 1951) of the *Journal* giving volume, page, plate, figure, age, and locality for each entry and including also taxonomic categories above the genus-level. It is thus intended to result in a reference catalogue rather than becoming an ordinary general index.

14. *Report on Carbonate Rocks Symposium* (*R. J. LeBlanc*).—A symposium on "Regional Aspects of Carbonate Deposition" was held in connection with the 1954 S.E.P.M. convention in St. Louis and the following papers were formally presented:

"The Distribution of Marine Carbonate Sediments"—JOHN RODGERS

"Calcium Carbonate Deposits of the Great Bahama Bank, British West Indies"—NORMAN D. NEWELL AND J. KEITH RIGBY

"Early Diagenesis and Lithification of Carbonate Sediments in South Florida"—ROBERT N. GINSBURG

"Mississippian Carbonate Deposits of the Ozark Region"—RAYMOND C. MOORE.

Manuscripts of the four papers listed above were submitted to the writer in 1954 and 1955, and plans to publish these papers,

together with a complete record of the panel discussion (which includes contributions from L. V. Illing and R. W. Fairbridge) were submitted to the S.E.P.M. Council in the fall of 1955.

In October, 1955, the symposium material was submitted to the George Banta Company, Inc., for an estimate of printing the symposium in a special volume. According to the George Banta Company, Inc. the various manuscripts indicate a book of approximately 192 pages, including numerous illustrations. The cost for publication of this special volume would be approximately $3292 for 1000 copies and $3985 for 2000 copies. On the basis of this cost information, Mr. R. H. Dott, Business Manager, has estimated that the recommended selling price to members would be $5.00 if only 1000 copies are printed and sold, and $3.50 if 2000 copies are printed and sold. This information was submitted to the S.E.P.M. Council, and on October 28, 1955, the writer received approval to proceed with publication of the symposium material as a special publication of the S.E.P.M.

Early in 1956, the various authors were notified that their material was in the process of being edited and would appear as soon as possible as a special volume. This editing job is now approximately half completed and the writer hopes to have it in final form and submitted to the printers in approximately 60 days.

15. *S.E.P.M. President's Report* (*Francis J. Pettijohn*).—The finances of our Society are in good shape and we ended the fiscal year with a surplus. This was accomplished by a raise in dues and by a more equitable sharing of expenses with the Paleontological Society in the publication of the *Journal of Paleontology*. Our bettered finances are the fruit of the labors of a previous administration and of the Russell Committee to whom we are indeed grateful.

The past year saw the reprinting of *Recent Marine Sediments*. This publication, originally sponsored by the American Association of Petroleum Geologists, has been turned over to our Society for reprinting and distribution. *Finding Ancient Shorelines*, a symposium given in Houston in 1953, was also printed and released as a Special Publication. Scheduled for early appearance is the symposium on carbonate deposits presented in St. Louis in 1954. Much to be regretted is the delay between presentation of the papers and their release as a special publication. This lag, discouraging to contributors and editor alike, is due primarily to shortage of funds. Our Publication Fund has been earmarked too far in advance and is replenished so slowly by sales that publication of new material is far too long delayed. During the past year the Publication Fund was augmented by a gift of $884.28 from the New York Oil Finders Convention Committee, which was our pro-rata share of the surplus remaining from the 1955 joint annual meeting in New York. This gift is a most welcome addition to our Publication Fund.

Our membership continues to grow, a ten per cent increase being recorded during the past calendar year. Although this is a reasonable increase, our membership is still much below what it should be to support our program of activities. Forty papers were presented on the S.E.P.M. program in New York; 62 papers were presented on the A.A.P.G. program. Yet S.E.P.M. has less than one tenth the membership of the A.A.P.G.! And many who participate in our programs and read our journals are not members of our Society. Clearly there is a job for an energetic membership committee!

It is with regret that we accepted the resignation of A. K. Miller as co-editor of the *Journal of Paleontology*. As our journals are perhaps our most important undertaking, the editors are therefore our most important officers. We are indeed grateful to Dr. Miller for his efforts in our behalf. We are pleased that co-editor W. M. Furnish will carry the editorial responsibilities for the remainder of this year. Unfortunately for our Society, Dr. Furnish would like to be relieved of his duties at the end of his term. J. L. Hough has returned to active duty as editor of the *Journal of Sedimentary Petrology* after a two years, absence from the country. We are pleased to have him back and are grateful to R. E. Grim for serving as Acting Editor during Dr. Hough's absence.

It appears to some of us that our method of selecting our presidents is not wholly satisfactory. By recent amendments to our constitution and by-laws, only those who

have previously served the Society as editor, secretary-treasurer, vice-president or as chairman of the Research Committee are eligible for nomination for president. This restriction has the merit of giving us candidates with previous contact with Society affairs, which makes for a more effective and efficient discharge of the presidential duties. Unfortunately, our pool of candidates is not very large and tends to shrink. The editorships, and commonly the positions of secretary-treasurer and chairman of the Research Committee do not rotate, so that in many years only one new name is added to the roster of those eligible for the presidential nomination. As two are nominated each year and only one elected, the pool diminishes quite rapidly. Defeated candidates are not prone to stand for election a second time; others refuse to stand for election even one time. Some become professionally inactive or even drop out of the Society. A special committee, consisting of Stuart A. Levinson, chairman, W. C. Krumbein, and Grover E. Murray has been appointed to look into the situation and to suggest constructive action. This committee will report to the Council at its April meeting in Chicago.

Most scientific societies are affiliated with the American Association for the Advancement of Science. The American Association of Petroleum Geologists is so affiliated but our Society is not. It was deemed advisable to look into the matter of affiliation to see what privileges and responsibilities were involved. To do so a special committee consisting of Chalmer Cooper, chairman, J. Marvin Weller and H. N. Frenzel was appointed. This committee will report to the Council at its April, 1956 meeting.

W. D. Pye, our representative on the Glossary Project, asked to be relieved of his duties. His request was granted and Jules Braunstein agreed to assume the responsibilities as our representative. Assisted by R. L. Corbeille, R. H. Clark and McLain Forman, he brought our participation in the Glossary Project to a successful conclusion.

We received a request from the Society of Vertebrate Paleontologists for support of a postion taken by them respecting interpretation and administration of the "Federal Antiquities Act" an act passed by the Congress to regulate the collecting of antiquities on the public domain. The S.V.P. expressed the view that the intent of Congress was the regulation of the collection of archeological materials and that fossils were not "antiquities" as ordinarily defined. The Council considered the matter and went on record as concurring in this interpretation and supporting the appeal by the S.V.P. for an administration of the act thus construed.

Your president recommends that more positive steps be taken to better integrate the operation of the Society with that of the several sections. There is too little communication between these sections and the parent organization. To further better relations the presidents of the several sections have been invited to meet with our Council this April.

The provision that the vice-president assume full responsibility for the Annual Meetings of our Society has worked very well. We are very grateful for the efforts of our vice-president and his technical program committee for the excellence of the papers and symposia presented at Chicago this year. Special mention should also be made of the activities of the Research Committee for the organization of a symposium for these meetings and for the selection of the "best paper" awards. This committee has under consideration plans for small informal regional conferences on current research problems and progress.

Appointments made during the year include the two nominating committees, one consisting of C. C. Church, Chairman, M. N. Bramlette, and S. G. Wisslar, and the other consisting of S. A. Levinson, Chairman, H. A. Ireland, and M. A. Hanna. Other appointments include E. C. Dapples as General Chairman for S.E.P.M. and member of the Steering Committee for the 1956 joint annual meetings, J. M. Weller as Presiding Officer, for S.E.P.M. at the joint session in Chicago, Raymond Siever replacing E. C. Dapples as Chairman of the Research Committee and W. J. Plumley as a member of this committee, H. R. Wanless as S.E.P.M. delegate at the 50th centennial celebration of the Illinois State Geological Survey, Hans Thalmann as delegate to the XXth International Geological Congress at Mexico City this year, R. C. Moore as the S.E.P.M. representative on the committee for the preparation of the *Treatise on In-*

vertebrate Paleontology, and the various chairmen and co-chairmen of the technical sessions of our annual meeting, and W. M. Furnish, Chairman, C. W. Stuckey, Jr., and F. M. Swain as the Resolutions Committee for the annual meetings. W. M. Furnish was appointed Conferee to meet with the Council of the Paleontological Society at New Orleans in November, 1955.

It was moved, seconded, and carried that the above reports be approved and that they be published in the Society's publications.

The following change in the S.E.P.M. By-Laws was presented to the business meeting:

ARTICLE X. RESEARCH COMMITTEE

2. The activities of the Committee shall be directed by a chairman and a vice-chairman, to be appointed by the president, *with the approval of the council*, from the *active* members of the Committee. *The term of the appointment of the chairman shall be one year.* In the event either of these offices is vacated for any reason, the [president] *council* shall appoint a qualified replacement of the unexpired term.

The foregoing change was approved by a unanimous vote.

The meeting was turned over to incoming President Robert R. Shrock.

The Resolutions Committee, composed of W. M. Furnish, chairman, Fred M. Swain, and Charles W. Stuckey, presented the following "Resolutions of Thanks."

BE IT RESOLVED THAT in behalf of the Society we extent an expression of our sincere thanks to the following:

TO ROBERT R. SHROCK, chairman, and the members of the S.E.P.M. Technical Program Committee and to the speakers for the high quality of the papers on the 1956 program;

TO EDWARD C. DAPPLES, general chairman of the S.E.P.M. convention, for his capable handling of the details of the meeting;

TO RAYMOND SIEVER, Chairman of the Research Committee, and the members of his committee, for the excellent research symposium on Directional Properties of Sedimentary Rocks;

TO CHARLES COLLINSON, for arranging the session on Paleontology and Stratigraphy;

TO HARRY S. LADD, for preparation of the program dealing with Paleoecology;

TO LEWIS M. CLINE, for arranging the papers on Mineralogy and Sedimentary Petrology;

TO M. M. LEIGHTON, general chairman of the convention, and to the chairmen and members of all the convention subcommittees for effective leadership and organization of the Chicago meeting;

TO THE EXECUTIVE COMMITTEE of the A.A.P.G. for appropriating $1500.00 as office rent for the Society Headquarters at Tulsa;

TO ROBERT H. DOTT, for his valuable service to the Society as its Business Manager;

TO MRS. RUTH TENER, headquarters secretary, for continued interest and care of society affairs;

TO RALPH E. GRIM, who served as Acting Editor of the *Journal of Sedimentary Petrology* during the period February, 1954, to September, 1955, for his assumption of full responsibility for the *Journal* during the absence of the Editor;

TO A. K. MILLER, who served as Co-Editor of the *Journal of Paleontology* during the period January, 1955, to December, 1955;

AND TO THE CONRAD HILTON HOTEL, for providing such excellent meeting and Headquarters facilities.

It was moved, seconded, and carried that the above Resolutions be adopted.

The business session adjourned at 6:00 P.M., Tuesday, April 24, 1956.

PACIFIC SECTION

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

Nov. 10 and 11, 1955, Biltmore Hotel, Los Angeles, Calif.

Thursday Evening

S.E.P.M. ANNUAL DINNER AND EVENING SESSION

Presiding: HAROLD G. BILLMAN, President, Pacific Section, Society of Economic Paleontologists and Mineralogists, Union Oil Company of California, Bakerfield; AND E. H. STINEMEYER, Secretary-Treasurer, Pacific Section, Society of Economic Paleontologists and Mineralogists, Shell Oil Company, Bakersfield

FORAMINIFERAL ZONATIONS IN THE TERTIARY SEQUENCE OF SOUTHWESTERN WASHINGTON

WELDON W. RAU

U. S. Geological Survey, Menlo Park

Detailed stratigraphic and foraminiferal studies of the Tertiary rocks of southwesrtern Washington are being made by the U. S. Geological Survey to provide more precise correlation and dating of these coal-bearing and potential oil-bearing strata. Foraminiferal zonations based on these studies have been established for a thick but poorly exposed sequence of rocks that is characterized in part by rapid lateral and vertical changes in lithofacies and in part by similar lithologies in rocks of different ages. In places correlations are hampered by intercalated volcanic flows.

Thirteen measured surface and subsurface sections that are believed to be representative of the Tertiary rocks in southwestern Washington have been used as the basic framework for dividing these rocks of Eocene, Oligocene, and Miocene (?) age into eight foraminiferal zones. Faunal characteristics of each zone are discussed and stratigraphic limits assigned on the basis of highest and lowest occurrences of species. The assemblages are compared with known faunas of the Pacific Coast and particular consideration is given to those referred to Laiming's Eocene zones of California and Kleinpell's Oligocene and Miocene stages of California. Faunal similarities suggest regional correlations and age determinations ranging from possibly as low as Laiming's Eocene B-2 zone of California to Kleinpell's "Oligo-Miocene" Saucesian stage of California.

Friday Morning

Presiding: E. H. STINEMEYER, Shell Oil Company, Bakersfield

1. FORAMINIFERA OF SANTA CRUZ BASIN

JOHANNA RESIG

University Southern California

Santa Cruz Basin is one of the many basins composing the unique offshore area known as California's "Continental Borderland." The basin is located to the south of Santa Cruz Island and reaches a depth of over 6400 feet. A difference in depth of 2900 feet between the sill and the basin bottom provides for a large area of relatively uniform conditions below the sill. Santa Cruz Basin, therefore, serves as an ideal location for the study of the effects of a basin environment upon foraminiferal distribution.

From a series of bottom samples taken at depths ranging from 450 to 6120 feet within the basin, a study of the living and dead foraminifera was made. At the sill, *Bolivina minuta, Cassidulina cushmani, Cassidulina delicata, Epistominella* sp., and *Virgulina nodosa* were found living, with all but the latter well represented in the dead population. In another sample taken near sill level but at the side of the basin, additional living species were *Volivina spissa, Epistominella smithi, Globobulimina pacifica, Pullenia salisbury, Uvigerinaiperegrina, Valvulineria inaequalis,* and *Virgulina seminuda.*

Comparing the assemblage at or above sill level with the foraminifera living in the basin depths, it was found that only one species was living near the bottom which was not also living near the sill. In three samples taken well below sill level, *Chilostomella ovoidea, Epistominella* sp., *Epistominella smithi, Fissurina marginata* var., *Globobulimina pacifica,* and *Uvigerina peregrina* were found living. While *Chilostomella ovoidea* was restricted to the deeper waters, and *Fissurina marginata* var., and *Globobulimina pacifica* to depths from just above the sill to the bottom, their tests are not correspondingly abundant among the dead populations. This could be attributed to a number of factors including slower reproductive habits of the species, or migration. Forms abundant in the dead population which were not found to be living are *Bolivina minuta* and *Cassidulina delicata.* It is possible that displacement down slope has occurred as the species were found living at a higher level.

Trends which were noted in vertical distribution include: (1) a decrease in the number of genera and species with depth, with a pronounced reduction below sill level; (2) a decrease in the number of living individuals in 100 grams of sediment with depth (at sill level and below, there are three to sixteen, and above sill level, five to 275 individuals per 100 grams); (3) a general decrease in the percent of planktonic tests with depth (above sill level, the average plankton content is 54%, while below this level, it is 23%).

2. A RESTUDY OF THE MOHNIAN-DELMONTIAN CONTACT NEAR CALABASAS, CALIFORNIA

F. W. Bergen, Jr.
Shell Oil Company, Bakersfield

The type localities of the *Bolivina hughesi* zone of the upper Mohnian and the *Bolivina obliqua* zone of the lower Delmontian, as defined by R. M. Kleinpell, are on the north flank of the Santa Monica Mountains along Topanga Canyon Road. Because of a scarcity of foraminifera between the good *Bolivina hughesi* faunas and the good *Bolivina obliqua* faunas, the contact between the two zones was based on a lithologic change within the barren zone.

Subsequent sampling in the vicinity of the type sections by M. L. Bramlette produced scattered foraminifera, among which were species found in neither the *Bolivina hughesi* nor *Bolivina obliqua* faunas. There was a suggestion of a new zone comprising the "barren" sequence between Kleinpell's zones.

A restudy of the entire sequence of zones, three miles to the west near Calabasas, was begun in 1951. In the Calabasas area, between the highest *Bolivina hughesi* fauna and the lowest *Bolivina obliqua* fauna, are 730 feet of shale with numerous thin beds of limestone. The shale outcrops of this interval are barren, as they are in the type section, but the limestone beds contain a very distinctive fauna. Some of the species characteristic of the fauna are: *Cassidulinoides californiensis, Pulvinulinella purisima, Virgulina californiensis* var. *grandis*, and *Virgulinella pertusa*. The conclusion drawn is that the relatively barren beds heretofore assigned to the top of the *Bolivina hughesi* zone and the lower part of the *Bolivina obliqua* zone should be given zonal status intermediate to those zones. For the present, the interval is given the name Intermediate zone.

3. UPPER AND MIDDLE MIOCENE FORAMINIFERA FROM SOUTHEASTERN PART OF THE LOS ANGELES BASIN, CALIFORNIA

Patsy Smith
U. S. Geological Survey, Pomona College, Claremont

In the southeastern part of the Los Angeles Basin (Santa Ana Mountains, San Juan Capistrano area, and San Joaquin Hills) thick sections of upper and middle Miocene sedimentary rocks are exposed. Foraminifera have been collected and studied from five geographic units: the northern and central Santa Ana Mountains, the southwestern Santa Ana Mountains, the east flank of the Capistrano syncline, the west flank of the Capistrano syncline, and the Newport Lagoon area. The faunal assemblages of each area are compared with the California Miocene stages proposed by Kelinpell in 1934.

The upper part of the Topanga formation contains faunas of middle Miocene (Relizian ? stage) age. The Topanga formation is overlain by rocks varying in age from middle Miocene (Luisian stage) to upper Miocene (Mohnian stage).

In the northern and central Santa Ana Mountains, the Topanga formation is overlain by the Puente formation of upper Miocene age.

In the southwestern Santa Ana Mountains, north of the town of El Toro, the Topanga formation is overlain by a thin section of the Puente formation. Faunal correlations within the Puente formation in this area are very poor, shallow-water forms predominating.

In the Capistrano syncline, south of the El Toro air station, the Topanga is overlain by the Monterey shale, On the east flank of the syncline the Monterey shale consists of about 100 feet of rocks of the upper part of the Luisian stage and about 1200 feet of rocks of the Mohnian stage.

On the west flank of the syncline, the Monterey shale consists of about 20 feet of rocks assigned to the lower part of the Luisian stage, about 320 feet of rocks assigned to the upper part of the Luisian stage, and 0 to 200 feet of rocks of the Mohnian stage.

At Newport Lagoon the Topanga is overlain by rocks of the Monterey shale assigned to the Luisian and Mohnian stages.

Changes of thickness of rocks assigned to Kleinpell's Luisian and Mohnian stages are due to uncomformities and local depositional variations. No evidence was found to indicate that foraminiferal faunas assigned to the Mohnian stage grade laterally into faunas of the Luisian stage.

4. EOCENE DIATOM FLORULES OF THE KELLOGG AND SIDNEY SHALES, MT. DIABLO AREA, CALIFORNIA

Taro Kanaya
Scripps Institution of Oceanography, La Jolla

This paper describes diatom species of Eocene shales from two different horizons, the Kellogg and Sidney shales, in Mt. Diablo area, and establishes a local standard diatom sequence of the "Kreyenhagen shale" in California.

The shales occur in the area north and northeast of Mt. Diablo, middle California; the Sidney shale is a middle member of the Markley formation, and the Kellogg shale is believed to lie below the Markely formation. Eighteen samples, nine from the Kellogg and nine from the Sidney, all collected in the same sections from which

Clark and Campbell described the radiolarian faunas, are selected for the present study to represent 85 feet of the Kellogg shale and 90 feet of the highly diatomaceous part of the Sidney shale.

Thirty-nine species, including one new, are described from the samples, and the relative abundances of the species are summarized in a chart which shows the diatom assemblages of both shales in sequence. On the basis of this distribution, and their previous records of occurrences mainly in California, seventeen species, all common to the Kellogg and Sidney shales, characterized positively the Eocene Mt. Diablo florules here discussed from those of the Cretaceous and Miocene, previously reported from California localities.

The chart is analyzed from statistical aspects, and it is found that, by using the characteristic seventeen species, the samples of the two different stratigraphic units, the Kellogg and Sidney shales, can be distinguished objectively, in terms of the relative abundances and joint occurrences of the species.

5. LOWER CRETACEOUS STRATIGRAPHIC UNITS OF NORTHERN CALIFORNIA

MICHAEL A. MURPHY
University of California, Riverside

A thick succession of fossiliferous Lower Cretaceous clastic rocks crops out near Ono, California. Although these rocks have been studied by California geologists and paleontologists for almost 100 years, no detailed maps or sections have ever been published.

This district is the type area for the stratal unit previously called the Horsetown "group" or "formation," here redefined as the Horsetown stage. Eight biostratigraphic zones, ranging in age from Hauterivian to late Albian in the European time scale are defined within this stage. The upper and lower boundaries of the stage are defined by the bases of the zones of *Pervinquieria hulenana* and of *Neocraspedites aguila* respectively.

Two new formations are recognized within the mapped area; the Rector formation, a thin sandstone and conglomerate unit, is markedly transgressive and lies upon the igneous and metamorphic rocks of the Klamath Mountains; the Ono formation, a thick mudstone unit with two coarse clastic tongues, lies on the Rector formation and underlies unnamed conglomerate units of probable late Albian age. The rocks of the Ono formation are predominantly mudstone with nodular limestone; graywacke and conglomerate comprise about 30 per cent of the section. The boundaries of the lithologic units are not coincident with those of the Horsetown stage.

A southeast-dipping homocline complicated by numerous small and several larger transcurrent faults is the main structural feature of this area.

6. SOME FORAMINIFERA FROM ROCKS OF EOCENE AGE ON SAN NICOLAS ISLAND, VENTURA COUNTY, CALIFORNIA

MERLE C. ISRAELSKY
U. S. Geological Survey, Menlo Park

San Nicolas Island is the most seaward of the Channel Islands which lie off the coast of southern California. It consists of Eocene sandstones and siltstones that form a complexity faulted anticline. Except along the sea cliffs the Eocene strata are generally mantled by marine deposits of Pleistocene age, sand dunes, and Indian kitchen mounds.

Faunal collections from a number of measured sections are used in an attempt to establish correlations and zone the outcropping Eocene. The Eocene rocks appear to be equivalent in age to the Kreyenhagen of the San Joaquin Valley.

ANNOUNCEMENT

S.E.P.M. PROGRAM FOR ST. LOUIS MEETING

APRIL 1–4, 1957

The Society of Economic Paleontologists and Mineralogists is planning a program for the St. Louis 1957 meeting which will consist of the following:

1. A joint session with the A.A.P.G.

2. A session of volunteered papers on paleontology and stratigraphy, with Shepard W. Lowman, Rensselaer Polytechnic Institute, Troy, New York, as Chairman.

3. A session of volunteered papers on sedimentary mineralogy and petrology and sedimentology, with Sherman A. Wengerd, University of New Mexico, Albuquerque, as Chairman.

4. A symposium on "Biostratigraphy," with emphasis on the role of evolution in stratigraphic paleontology, to be organized by the Research Committee, with Curt Teichert, U. S. Geological Survey, Federal Center, Denver, Colorado, as Chairman.

5. A symposium on "Geochemistry of Sedimentary Materials" is tentatively

planned, with William J. Plumley, California Research Corporation, La Habra Laboratories, La Habra, California, and Heinz A. Lowenstam, California Institute of Technology, Pasadena, as Co-Chairmen.

All persons interested in submitting papers for this program or who have suggestions for the symposia should write directly to the Chairman of the particular session.

November 1 is the deadline for the submission of abstracts and papers for any part of the program. We earnestly solicit your cooperation and aid in order that we may organize and carry through what we hope may be one of our outstanding programs.

R. V. HOLLINGSWORTH
Chairman, Technical Program

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